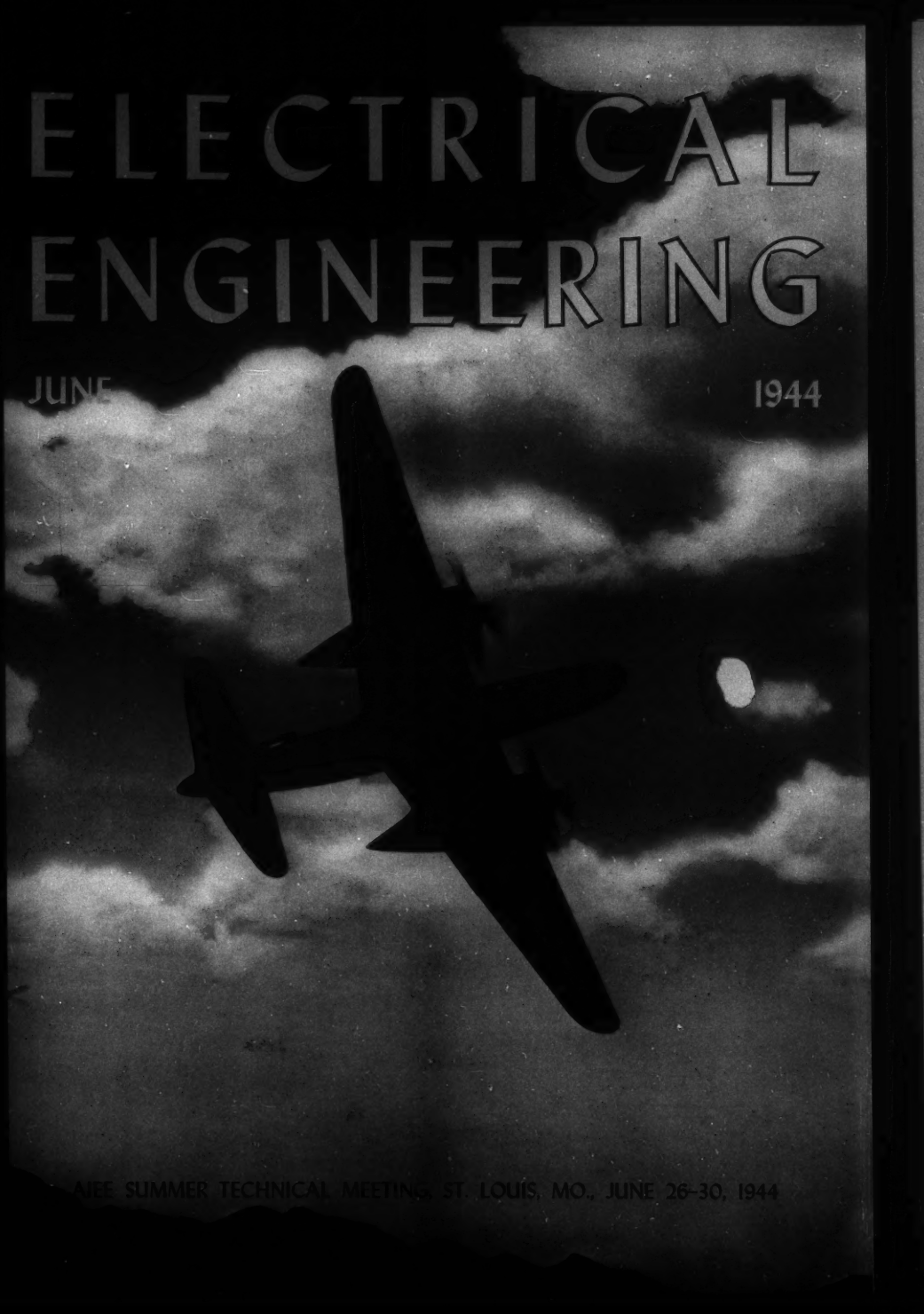
ELECTRICAL ENGINEERING

JUNE 1944



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Transflex tubing withstands repeated deformation by the cam used to start, reverse or completely stop the flow of ink from reservoir to pen. It also is resistant to the cam and recess lubricant. (Partially assembled, underside view.)

Transflex rods, at the points shown, absorb over 56,000 jolts in five minutes when the necessarily sturdy, oscillating pen records messages at 400 words per minute.

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Insulated Wires and Cables

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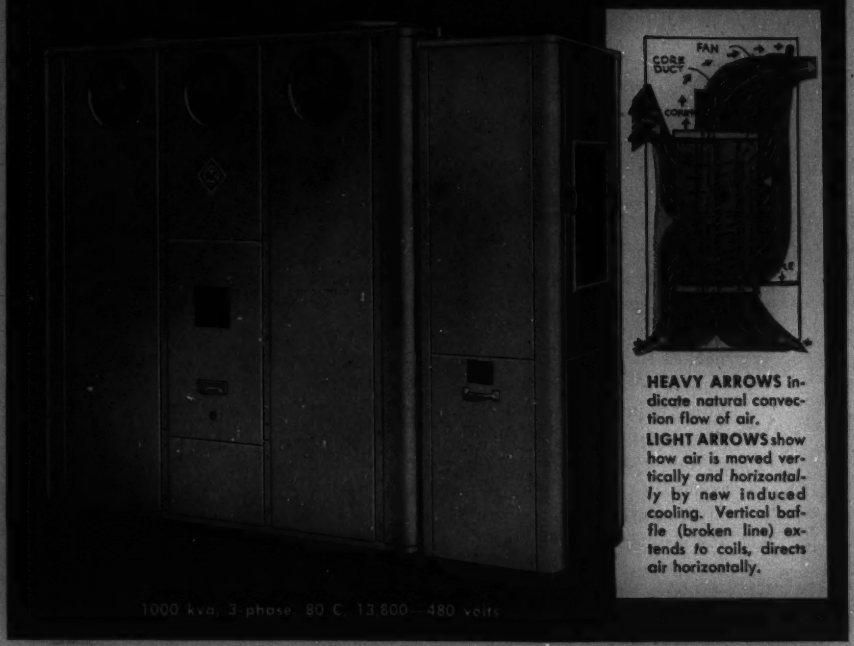
OK — *A signal flashed by telegraphers indicating message got through.*

O- — *To aid in pronunciation.*

NITE — *A suffix used in the early days (as in "vulcanite") to signify "insulation".*

PRODUCT OF THE MONTH

New Allis-Chalmers Dry-Type Transformer with Induced Cooling (Rear View)



HEAVY ARROWS indicate natural convection flow of air.
LIGHT ARROWS show how air is moved vertically *and horizontally* by new induced cooling. Vertical baffle (broken line) extends to coils, directs air horizontally.

MILWAUKEE, WIS.—Allis-Chalmers announces a newly designed Dry-Type Transformer with *induced cooling*. Fans—automatically controlled by temperature — and a system of baffle plates make this new streamlined transformer ideal where peak power loads prevail. Write for B-6334 today.

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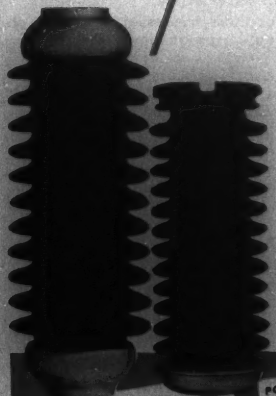
is the fastest way to fortify your system.... and uses least materials

New or increased load demands frequently can most efficiently be handled by conversion of existing lines to higher voltage. For this job, Lapp Line Posts are particularly suited. Using present sound poles and conductors, conversion to higher voltages can be accomplished with no more than new cross-arms and Lapp Line Posts. Nor need such construction be considered as an emergency temporary expedient. Such a line approaches the current ideal for a new line; and your Lapp Posts can be expected to give trouble-free service for a longer period of years than you ever got from conventional insulators.



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POWER ARCOVER. Flashover and leakage distances are not appreciably lowered by damage —even loss of several petticoats.

NO PUNCTURE. Puncture path in Lapp Post design is as great as flashover path. Insulator will flash over rather than puncture.

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MECHANICAL RUGGEDNESS. Stones or bullets deflect off, or rupture petticoats, leaving post body intact and insulator secure.

VALUABLE INFORMATION

on

Applications of Insulating Varnishes

A new seventeen page booklet on "Applications of Insulating Varnishes" has just been published. In this booklet, there is valuable technical information on preheating of electrical units, treating the units with insulating varnish through means of both vacuum and atmospheric impregnation together with data relating to the selection of baking cycles.

Also included is a chart showing the saturated vapor pressure of water at sub-atmospheric pressure. This chart shows that the boiling of water is possible even at a temperature of 34°F. depending, of course, upon the pressure. If the surrounding pressure is reduced by virtue of the vacuum created, the ratio of the evaporation of the moisture to the condensation is increased. The vapor pressure will be considerably lower, thus fostering maximum evacuation of moisture in deep coil interiors.

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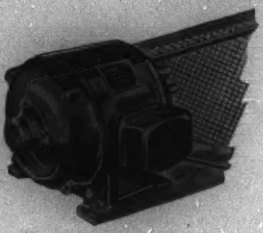

Greatly accelerated production, to meet wartime schedules, often means overloading of electric motors.

That this can be done without frequent breakdown is a tribute to both the motors and their manufacturers. But some motors have stood up better than others. Many of those with outstanding performance records are insulated with varnish - impregnated *Fiberglas* — the glass - fiber insulation.

An exclusive combination of inherent qualities makes impregnated Fiberglas a better electrical insulating material; highly efficient and with the ability to provide an extra "safety factor" against such unanticipated abuse as unusual overload.

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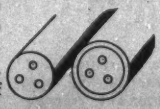

Other basic properties of Fiberglas are: high tensile strength —resistance to acids (except hydrofluoric), oil and corrosive vapors—non-hygroscopic, does not absorb moisture — high thermal conductivity in textile form—permanent—does not deteriorate with age—dimensional stability.

All these properties contribute to longer life and better service for electrical equipment. They make Fiberglas insulation an outstanding value.

May we suggest that you get all the facts about this better electrical insulation. Write *Owens-Corning Fiberglas Corporation, 1859 Nicholas Building, Toledo 1, Ohio. In Canada, Fiberglas Canada, Ltd., Oshawa, Ontario.*

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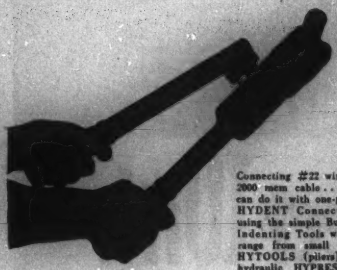

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ELECTRICAL ENGINEERING

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JUNE

1944

The Cover: This new Douglas P-70 night fighter, an adaptation of the A-20 attack bomber, carries four 20-millimeter cannons. Electric equipment on military aircraft will occupy four sessions at the AIEE 1944 summer technical meeting (*pages 221–3*).

Photo courtesy Institute of the Aeronautical Sciences

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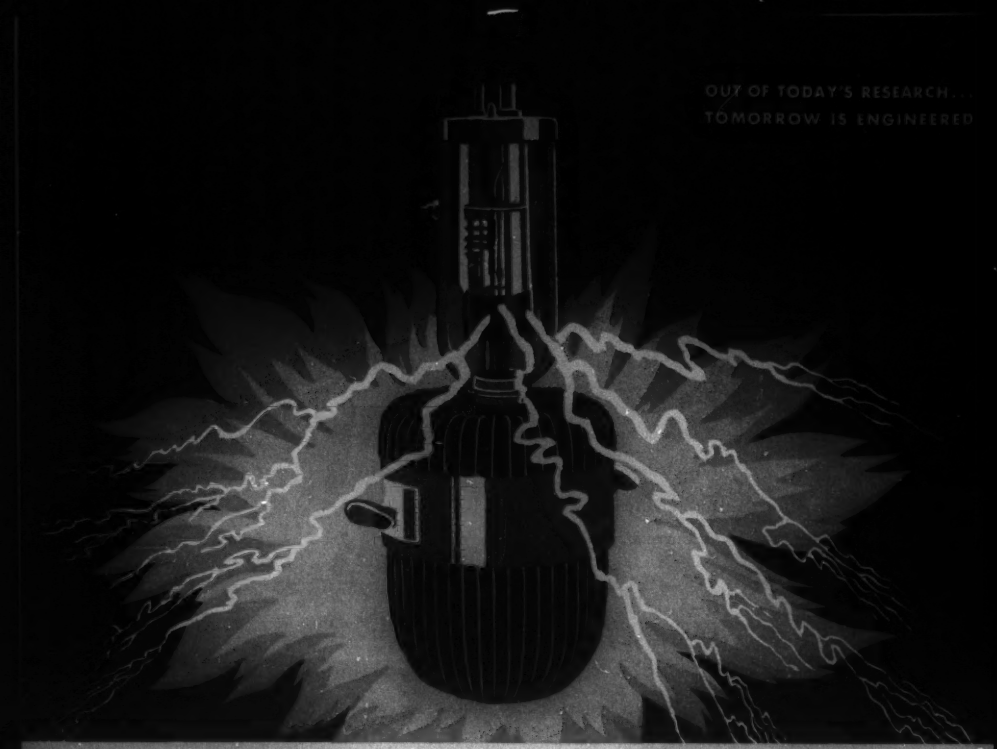
OUT OF TODAY'S RESEARCH...
TOMORROW IS ENGINEERED



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ELECTRICAL ENGINEERING
VOLUME 63, NUMBER 6 JUNE 1944

Meteorological Service for Electric-Power Systems

A. E. DAVISON
ASSOCIATE AIEE

Special forecasts for electric-power companies and wider dissemination and more effective use of these forecasts are advocated in this article. Effects of glaze storms, lightning, hurricanes, magnetic storms, fog, flood, precipitation, and high and low temperatures on electric service are discussed.

THE ADVISABILITY of providing special weather forecasts for utilities and utility engineers, including communication and transportation organizations, was suggested by weather forecasters and climatologists early in 1943. It was recommended that utility engineers should indicate what special features of weather forecasts would make these predictions of special value to them.

As far back as 1934 and as recently as May 1940, conferences held in Harrisburg, Pa., by the Pennsylvania Electric Association,* and in Washington, D. C., aimed at the establishment by the electric utilities of additional weather-observing stations in those areas and greater dissemination and more purposeful use of weather forecasts. Assembly and dissemination of weather records by means of commercial teletype communication was recommended, a practice well-established in civil aviation in Canada, since an official typed record has certain advantages over oral or unrecorded communications, and receipt of teletype messages does not take employees away from other duties.

At the Harrisburg conference, a co-operative movement was set up whereby four observations would be taken by the electric utilities each day at 5 and 5:30 a.m. and at 2 and 2:30 p.m. Arrangements were made so that, in the Pennsylvania area, cloud cover, temperature, wind direction and velocity, and time of beginning and end of precipitation, would be furnished by the electric utilities from nine stations. These reports would be called for at centralized points by the weather bureau at 5:50 a.m. and 3 p.m. Special early-morning forecasts then would cover sky conditions, time and character of fog or precipitation, maximum and minimum temperatures, significant air movements, thunderstorms, glaze, humidity, and important air-mass movements for that day. Employees would be instructed in using these forecasts for establishing electric-service security and would learn the definitions, terms, and code procedures used by the meteorological office. At one of these conferences, the issuing of four Government weather maps per day was announced for some parts of the country.

* The systems operation committee of the Pennsylvania Electric Association, under the chairmanship of W. R. Hamilton, West Penn Power Company, Pittsburgh, Pa., and more recently under the chairmanship of E. W. Middleton of Pennsylvania Power and Light Company, Hazelton, Pa., has studied weather quite extensively during the past five years. A report on the work of this group may be secured from the Edison Electric Institute, New York, N. Y.

The advantages of long-time forecasts of precipitation and associated subjects received attention recently in a paper by Doctor Merrill Bernard, dealing with the classification of the various types of storms and the principles determining the maximum probable storm occurring in a particular drainage basin. Recently, the English research organizations have established by experiment the value of the public co-operation in locating accurately the paths and boundaries of electric storms.

The purpose of this article is

1. To record the meteorological needs of the electrical industry.
2. To suggest what studies, forecasts, and recordings should be available for establishing greater security in supplying electric energy, water, gas, community steam heat, electric rail transport, communication, and other like services.
3. To indicate what has been done already on a commercial basis by interested private organizations.
4. To secure more reliable estimates of immediate and longer-time water-power resources and storage of precipitation.

NEED FOR METEOROLOGICAL DATA IN ESTABLISHING SERVICE SECURITY FOR ELECTRICAL CONSUMERS

If the service security is to be established for electrical consumers, forecasting is essential to electric utilities—especially short 4- to 12-hour forecasting of the incidence, coverage, severity, and the paths and speeds of all storm fronts and atmospheric disturbances, including magnetic, glaze, and electrical storms.

Glaze Storms. Glaze storms in the past have created the greatest insecurity and caused the longest interruptions to service and the most physical damage to electric-power properties. About the only recognized means of protection against the mechanical overloading of electric transmission conductors by glaze and sleet is internal warming of the conductors, sometimes limited in applica-

Essential substance of an address presented at a joint meeting of the AIEE, Toronto Section, and the Royal Meteorological Society, Canadian Branch, October 25, 1943, and at a joint meeting of the AIEE, Montreal Section, and the Engineering Institute of Canada, April 27, 1944.

A. E. Davison is transmission engineer of the Hydro-Electric Power Commission of Ontario, Toronto, Ont., Canada.

The author acknowledges assistance in the preparation of this article received from engineers associated with the Pennsylvania Electric Association.

The statements and opinions expressed in this article are the author's and shall not necessarily be construed as being those of his employer.

Figure 1. Number 2 copper wire ten days after storm at Van Hornesville, N. Y.

Ice has revolved with original icicles melting back and new ones forming

tion, since the necessary power current may not be available. If notice of from 4 to 12 hours is given for glaze or sleet storm, warming overloads frequently can be set up by rerouting of circuits, without great inconvenience to the stability and security of an electric system—even when the glaze deposits are only a probability. Two-to-four-hour notice of duration and severity of approaching storms would be sufficient for load despatchers instructed in rerouting of power and doubling up of electric loads on lines in the forecast areas.

This warming up of conductors is most effective and most easily done when glaze is forming, because the formation of ice or rime on the surface of the conductors at that time is very critical. There is considerable evidence that a change of temperature of a small fraction of a degree at the surface of a conductor will check or prevent the formation of glaze. Instances have been noted where a water film was found between the ice coating and the de-energized conductor during a short period of sunshine. Evidently there was enough absorbed and locally reflected solar heat at the dull corroded surface of the conductor to account for the loosening of the ice coating from the cold conductor. Sometimes because of gravity, the ice coating, having quite irregular cross sections and shapes, actually rotates 90 degrees or so on the conductor.

If forecasts covering an area are not available, the electric-supply utilities find it difficult to discover what is going on at the center of a 50-mile and in some cases a 275-mile length of line between terminals. The terminals both may be outside the sleet area, and yet, because of various types of excessive mechanical loads, failures can occur near the center of the section.

Even if operators fail to make satisfactory use of forecasting or find it impossible to reroute electric loads, it still is important that forecasts of temperature and of light and heavy winds be made available while the ice is on the conductor, for the patrol and maintenance group must be kept on the alert. Phenomenal motions of the conductors may be expected, and both electrical and mechanical failures are likely to occur because of the action of cross winds on the stream-lined cross sections of the glaze or on the partially coated surfaces of the wires. Under certain conditions, the wind tends alternately to lift and to depress the conductor, with the result that, at the middle of the span, the conductor may be found in quite unexpected positions.

While short-time forecasts—4 to 12 hours—are likely to be most authoritative, nevertheless the more normal forecasts—12 to 36 hours—soon should be sufficiently authentic to be useful, especially for glaze storms. Longer-range forecasting—weekly to seasonal or annual—and cyclic phenomena now are used by some utilities in determining water-storage and like system requirements.

Some electric-power utilities, co-operating with the limited weather forecasting already available, have set up operating procedures by which they "get ahead of the storm" and are eliminating, chiefly by load reallocation and rerouting, troubles expected during glaze storms.

Lightning. Thunderstorm days should be and are forecast, and, if intensities can be recognized by forecasters, then the more important storms should be featured in press and radio, but not necessarily to the extent that might alarm the average reader or listener.

At the present time lightning is the most frequent source of insecurity, outages, interruptions, and failures, within electrical works. Many actual interruptions to service due to lightning which affect the security of an electric system are of short duration; at times, however, important apparatus either is lost to the service or, requires an out-of-service period for repair. When lightning is forecast, some despatchers remove temporarily from their systems certain lines which are relatively sensitive or exposed to lightning.

Lately, important transmission lines and stations can be protected from the effects of most lightning discharges near or striking directly at the power wires by installation of overhead or grounded wires, which requires extra investments of 10, 15, or 20 per cent, sometimes amounting to millions of dollars. However, since there is no positive security against the effects of lightning discharges, special operating setups should be established, such as the planning and making immediately available of alternative routes, closing of loops, and similar short-time securities or operating defenses, when storms and storm paths are forecast.

Hurricanes. The curving path of a hurricane or tornado originating in the tropics frequently can be forecast with some accuracy on the North American continent; however, these occurrences are very infrequent. The New England storm of September 16, 1938 caused damage which warranted special investigation as far north as the easterly counties of Ontario. It is indicated as twice crossing main 220,000-volt routes in Ontario while breaking up on the morning of September 22.

Figure 2. Route 20, east of Sharon Springs, N. Y., seven days after storm

Ice one inch radial thickness and icicles

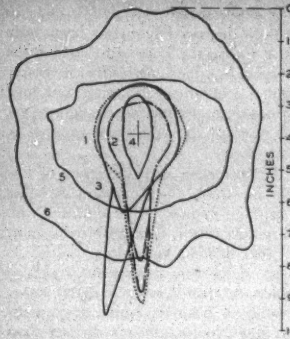

Figure 3. Chart recording ice deposits on wires

1—Number 2 steel-reinforced aluminum cable; storm—January 1–3, 1939; weight—3.3 pounds per foot

2—Number 10 copper wire; storm—January 1–3, 1932; weight—1.75 pounds per foot

3—336,400 - circular-mil steel-reinforced aluminum cable; storm—March 1922; weight—3.77 pounds per foot

4—Number 13 iron wire; storm—Michigan; weight—0.45–0.70 pound per foot

5—795,000-circular mil steel-reinforced aluminum cable; storm—December 1942; weight—7.14 pounds per foot

6—Number 4/0 copper cable; storm—New York; weight—14 pounds per foot

These loads apply to Ontario unless otherwise noted

Air-borne and marine traffic is rerouted, curtailed, and sometimes canceled on account of weather, but transmission works are always exposed, with the result that they generally are designed to carry the conductors, and a one-half-inch radial thickness of ice coating on them, together with a wind load equivalent to eight pounds per square foot on the cylinder. There are, of course, overload capacities in addition.

There should be available for design purposes an authentic record of the duration of and the areas covered by all winds in excess of 35 miles per hour along with coincident temperatures—in other words, an isoanemometric chart of lines recording the number of wind storms per year and their intensities. Some studies already have been made, the gaps in data having been filled in by estimations. The electrical societies are now arranging co-operatively for the dissemination of statistical information on the effect of wind upon operation and revenue.

Magnetic Storms. There are only a few recorded instances of magnetic storms which charged long power-supply lines electrically so as to cause relay operation. However, the electrical industry is still young, and the forecasting of this type of storm may require more attention in the future. The power-supply organizations are developing extensive communications of their own, costing in some cases as much as $1,000,000. This system is being set up in an effort to establish every type of auxiliary service which will tend to insure electric-power service. Such a telephone system, as well as the commercial communication systems, will need the forecasting of magnetic storms. All such communication services almost invariably are affected seriously by these storms. Alerts and reroutes around forecast storm paths and areas are again the most available defense.

Fog. Fog, mists, and damp periods at critical temperatures may be related to glaze deposits and also are a problem in themselves, especially after long, dry, or frosty periods.

Fogs have an important bearing on aviation. In tropical areas fog can now be forecast so successfully that the despatching of important commercial aviation services often is deferred or withheld, for the sake of the safety and comfort of passengers, because of forecasting of fogs over a long route by as much as 24 hours in advance. Fogs in temperate climates may not be forecast so readily.

The power utilities are interested in fog data, especially for the winter months, since during a period of cold weather there is an accumulation of certain chemical particles or deposits which are attracted to or which form on the electrically charged surfaces of insulators, especially in urban areas. As a result, when a fog or light rainfall is experienced at the end of a winter season, flashovers are likely to occur more frequently than at any other time except during lightning storms.

Broadcasting of Forecasts. Meteorological stations in some instances already have forecast important storms, especially those depositing ice, sufficiently in advance to give time to reroute electric energy for the warming-up of the conductors; however, some machinery should be set up by which, under peace conditions, advance notice of storms will reach operating employees at remote stations. Featuring and popularizing forecasts of glaze and other storms in radio reports of weather as New Zealand did before this war and as the American military authorities are now doing, would assist materially. An employee, responsible for certain lines and services and having means at his disposal for keeping conductors warmer than usual for several hours by overloading who experienced an interruption, would be aided in his work by advance radio or press reports that glaze troubles were imminent in the district. Once it is established that these forecasts are reasonably authentic and immediately available, it will not be long before every operator will become quite glaze-conscious and will make full use, through reroutes, alerts, and the like, of this information.

There appears to be no end to the problems which develop out of weather stress with which the operators of electric utilities must cope and which forecasters could visualize. For instance, all the staff members of a power utility should be trained in taking precautions against stress of weather and in having all reserve and repaired equipment immediately available for service. Adequate broadcasting of authentic forecasts will make electrical repair, maintenance, and operating employees more weather conscious.

CLIMATOLOGICAL

Floods, Precipitation, Runoff and Gauging Stations for Water Flow and Levels. There are available from the Weather Offices considerable data regarding precipitation, some of which are used regularly by industry.

The gauging of streams, and like assemblies of weather data are arranged by or are now in charge of either those interested specifically in these water levels or of Government departments other than the Weather Bureau. There may be some duplication. Many students of meteorology believe that the possible effect of runoff and storage and level of ground water on climatic conditions should receive more careful consideration; however, for the purposes of hydroelectric utilities this branch of the work appears to be fairly well taken care of at the present time.

The long-time forecasting of annual precipitation, extensive drought periods, the lowering of ground-water

levels, and the cyclic nature of these variations, if it can be established, is important to everyone interested in weather. Those interested in power utilities request further forecasting over long-time periods and thorough distribution of more authentic recordings.

State power regulatory bodies are now using continuous records of precipitation, as issued by the water resources branch of the United States Geological Survey, to the extent that they know at a given time the amount of snow which is still to melt and to be added to estimated rainfall. Someone will say they have established "isobrecheous" charts and lines. These surveys, which indicate the depth of snow on the ground and its water content, are used to estimate the probable water yield from snow cover during the ensuing spring runoff, and permit a forecast of the probable amount of water that may be stored.

The hydrometeorological section of the United States Weather Bureau, for three areas at least, has estimated the maximum possible precipitation—a very important forecast and estimate for engineers in charge of new water-power developments.

One of the earlier climatological researches which was made at the Experimental Farm at Ottawa was concerned with the extent, if any, to which agricultural soils are fertilized by snow water. This effect and an associated phenomenon—the effect which the absorption of losses due to corona and electric fields may have upon the surrounding air and on the soil when the resulting salts reach the earth—have never been reviewed thoroughly anywhere so far as the writer knows. All such information, in popularizing weather forecasts and recordings, could be assembled and distributed quite authoritatively by one organization. These data are frequently secured now for each watershed by different interests with some possible duplication—for instance, the same information might be secured by both the electric-power utilities and the foresters and lumbermen interested in spring log drives.

Figure 4. Float-type water gauge and well in forebay gatehouse

Long-Time Records of Temperatures—Frost Depths. Temperatures as low as −73 degrees Fahrenheit have been reported in Northern Canada. These are below the minimum temperatures for which designers of power and other utilities find it economical to design, but such low temperatures do not occur frequently enough, so far as is known now, to warrant the additional expense of designing especially for them.

Charts recording the incidence and frequency of low temperatures in areas in which electric power is being supplied should be kept up-to-date. The duration and extent of those low temperatures associated with snow coverage determine frost depths, and most utilities as well as agriculturists, need this information. Fence posts heave; so do poles and steel towers, the latter sometimes disclosing, because of heaving, quite unexpected forces. In northern areas, poles are set deeper than ordinarily in an attempt to minimize the effects of this distortion and strain.

Some of the facilities and weather data which are already established or are now being assembled and made use of by electric utilities and other private organizations might be used much more extensively if they were uniformly recorded, interpreted, and assembled, and disseminated both accumulatively and periodically.

The work done by L. J. Chapman on lines of highest and lowest recorded temperatures for an area, as reported in the *Canadian Geographic Journal*, September 1938, is an example of data that have been and can be issued under peace conditions. He records lines indicating the average number of days without killing frosts and other like information. These and other important charts should be kept up-to-date, giving the amount of precipitation to date as well as forecast, and should be issued periodically to power-supply utilities and similar organizations.

Glaze Racks. R. E. Jones of The Hydro-Electric Power Commission of Ontario standardized glaze racks in 1930. Some of these have been installed for observation in some of the northern United States and elsewhere and are being reported on by various interested persons It is intended that the glaze shall be melted off and weighed for some specific length of standard round wire and that the weight of ice per unit length of wire shall be computed. Record should be made of the shape and contour of peculiar glaze formations on these racks, although this is not being done at the present time.

Lightning Records—Incidence, Severity and Types. The Weather Bureau and other interests have assembled data by which isokeraunic lines have been projected throughout the continent. These lines are not yet accepted as sufficiently authoritative, and it is hoped that some organization qualified to do so will undertake the work of making available more authentic information within the next ten years. These isokeraunic lines, necessary as they are, always must be quite indeterminate, because some reporters are disposed to record lightning if, on some summer evening, they see the reflections of lightning in some distant sky, whereas others may be disposed to report lightning only when it strikes nearby.

Utility Log Sheets; Co-operative Weather Recordings—Code Work. Records of temperature, wind direction, and general statements regarding the weather, as one part of routine reporting, reach the head offices of electric

utilities from many generating and other stations where operators are called upon to record more specifically the electrical conditions within a system These data could be and are, in some instances, used by meteorologists; they should be reissued ultimately from the meteorological office as authoritative records over ten-year periods. Apparently some of these records now are telegraphed to headquarters in code, and short-time forecasts are returned.

STORM PATHS

Little work has been done on storm paths, and there appears to be much room for study. Of the available records, the more interesting features follow.

Effects of Geological Faults and Changes of Geological Structure. Small streams, sometimes flowing for a distance along geological faults or around the rim of a prehistoric or other tilted sedimentary basin, seem to account for more lightning flashovers on transmission routes which cross these areas than might be expected.

Very interesting studies have been made by French scientists on the interrelation of geological faults, normal air-earth electric currents, and lightning incidence; however, very little authoritative information has yet come from these studies, and more authoritative data are needed. This subject is open for further study and investigation by those who may have the time, opportunity, and interest in it.

Engineers recently have outlined in the English technical press local lightning experiences for which there does not appear to be any explanation other than geological and have been asking what effect geological formations and faults have on the incidence of lightning.

Storm-Path Records in Germany. Storm paths have been studied in Germany by Arendt and others, and some members of the meteorological services of the Reich comment favorably upon these efforts. If these reports can be relied upon, then it may be possible economically to lay out long transmission-line routes so that they will cross these major storm paths rather than parallel a concentration of them, wherever the terminals lie generally within a group of storm paths.

Storm Paths in Ohio. Brancato has recorded lightning storm paths in Ohio, many of which are straight line as in Arendt's work. Alexander has made somewhat similar studies some of which have not been published for that state.

Incidence of Flash Marks on Long Transmission Lines Varies With Geological Formation. Charts are available also which show the incidence of flashovers due to electric storms along a quite extended and important transmission route in Ontario; the incidence of these flashovers varies apparently with differing geological conditions. There is an excessive accumulation of flash marks which would appear to substantiate the statement that 80 per cent of flashovers are concentrated in certain areas constituting only 20 per cent of the length of the route. Charting storm paths and defining storm areas are two quite important items for operators of electric-supply systems, if the work by Arendt and others can be substantiated in other areas.

Personnel. Throughout the Allied countries, young men are being trained intensively as metallurgical technicians, as military store and equipment statisticians, and as expert weather forecasters. During the late 1930's the Reich was giving young Nazis training to go abroad to administer occupied countries. Great Britain at the present time is actively training carefully chosen young men to join the diplomatic services and to work as public-administration career men abroad just as soon as World War II is ended.

United States Weather Bureau photo

Figure 5. Glaze storm in Illinois, December 17 and 18, 1924

Today civil authorities might well select three or more students in each academic year who, by intensive study at home and abroad, could create weather recordings, services, and forecasts for and within electricity-supply and other like systems. In Southern California, employees, trained initially under Major Krick and now possessing a master of science degree in meteorology, serve the utilities as load dispatchers. The application of meteorological knowledge is reported as effecting considerable savings.

Some, who have studied this situation intensively, say that meteorological science, as it develops, will reach a point where no government agency will be large enough to handle all individual requirements of business and industry—a point where individual meteorological counsel and advice would become so valuable in the conduct of many businesses that it would pay to employ meteorological consultants.

Weather Reports During Wartime. This review deals with postwar needs. Meanwhile, the supreme problem is the war—nothing else matters now in a relative sense. Distribution of forecasts and weather records during wartime, of course, is quite limited. However, there is no reason why we should not soon make greater controlled use, in the civil services and in business, of the great advances in forecasting for aeronautical combat that have been made during this fairly long war period. Weather knowledge, a very important tool in postwar planning, should be at work now.

All this is in the nature of postwar planning; however, we should keep in mind the statement made recently by statesmen on this continent that postwar plans should be put into effect now. It is a matter of record that some countries are doing just that. Just now, weather information is assembled in some countries by such services

Figure 6. Recording equipment of diaphragm-type water gauge

as the meteorological office (prewar), civil aviation, military aviation, and privately controlled sources. All these presently should be combined to provide one improved authoritative service for all demands.

Radio, Radar, and Electronics. Several references to both popular and technical literature at the end of this article give some idea of the actual developments during wartime and of the postwar possibilities of radio and associated electronics in assembling weather data and in forecasting.

Popularizing Forecasting and Climatology. The joint task of engineers and meteorologists should be the popularizing of weather information. Making weather-conscious a public who have learned to take weather as it comes is important. Vetter in "Visibility Unlimited" has tried to popularize weather for airmen. He discusses new equipment, gives charts of rainfall, fog, and storm paths for the United States, and attempts to create weather-mindedness by pointing out what may be expected when observers find the temperature approaching the dew point. Thousands of active service men and women will return to civil life quite weather-conscious. Many of them of necessity have studied weather so intensively that with future training they might assist in some capacity, professional or otherwise, in meteorological undertakings which industry may initiate in the future.

One electrical supply organization, according to a contributor, has developed the following course of instruction for its operating staff. First, they review weather conditions prior to several more important sleet and glaze storms during which they were inconvenienced, as a guide and indication of what might happen in the next storm. In this review, they indicate the very critical nature of glaze formation since during that period very minor changes of temperature within the conductor will tend to keep glaze off its surface. Means of preserving transmission service once glaze has commenced to form on unheated objects are discussed, the principal procedures being short-circuiting and the use of higher-than-usual electric currents. They record, in their circular instructions, those stations from which, by arrangements in advance, information on glaze formation can be secured, and they recite those system and intersystem agreements which already have been issued to facilitate glaze rejection and removal.

Forecasts for Engineers, Utilities and Industry. There has been set up experimentally in one area a daily special forecast for a six-months trial period for engineers and industrialists. Matters in which the utilities appear to be most interested will be discussed and predicted more confidentially than is possible in the more routine forecasts. In each case, these forecasts will cover at least two succeeding days. During this trial period, the forecasters are expected to familiarize themselves with the requirements of the utilities, and there will be an opportunity to discover how closely to the engineers' needs a qualified forecaster can predict. Out of this co-operative effort, there might develop a routine service for all interested organizations.

A similar experiment in a more specialized forecast service for utilities will be conducted by the Weather Bureau in the Chicago area. Routine forecasts of a special co-operative nature have been made for electric-power companies in this area since 1940, but it is believed that a more personalized service and a better knowledge of the specific needs for weather service will result in further improvement. A rather comprehensive survey of the entire industrial forecast problem in this area was made in December 1943. It showed the value of forecast liaison work and also the need for group industrial forecast specialists.

What Can Electrical Utility Operators Do About Weather? As previously stated, planning engineers and load dispatchers can lay out and file in a dispatcher's office specific alterations of routine operation so as to create most satisfactorily both intersystem and intrasystem defences against a hypothetical but typical storm or against storms forecast in only one part at a time of the area served. These special operating setups can be used, for instance, for a glaze storm predicted as about to pass along a recognized storm path down a river valley, or for thunderstorms forecast as being segregated during the early part of a storm period to one side of a lake, and during the latter part of the storm period to the other side of that lake. So much for planning.

Once such a storm is definitely predicted by the meteorologists, the routine set up in advance can be established by the dispatcher, along with other evidently necessary preparations listed as follows:

1. Put everyone connected with the system on the alert, apart from whether they are on duty at that time or not.

2. Return all equipment under repair to service with temporary connections. Do this even for a noon-hour period and always for a week end.

3. Reroute commercial loads as promptly as possible to the temporary and inter-system setup that has been planned and from experience, which offers, in the opinion of the dispatcher, the best defense against the type of storm predicted.

4. Recall or temporarily assign vacationing and off-duty employees and like absentees to key positions or to strategically located reserve pools.

5. Man remote-control switches.

6. Notify important and interested customers to stand by for load adjustments without interruption of service, and for the possibility of accidental interruptions.

7. Stand by for forecast cancellations and revisions and for the all-clear weather notice before restoring normal economic-system operating setup.

What Savings May Be Effected if Maximum Advantage Is Taken of All Available Weather Information? Meteorolo-

gists, especially those on the Pacific Coast, have established substantial savings for agriculturists who avoided expense on account of what otherwise was an evident emergency due to drought. It is also reported that one manufacturing company saved approximately $10,000 annually by making use of predicted minimum temperatures. There may be opportunities of establishing similar savings within electrical utilities in future, since costs of restoration of lines and works sometimes amount to millions of dollars. All these restoration costs cannot be avoided by use of authentic weather information; however, part of most poststorm expense, inconvenience, and hazard could be saved or avoided, as in the case of the agriculturists.

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Industrial Research Under Free Enterprise

LOUIS RUTHENBURG

LET US first define our terms. "Industrial research" is subject to more than one interpretation, and so is "free enterprise."

In this discussion "research" will be used in its broadest aspect, without distinction between fundamental and applied research, between scientific and engineering research, or between research and technology.

Not long ago I asked Charles F. Kettering to tell me what he thinks is the most important aspect of research under current conditions. With characteristic simplicity and clarity, he said: "I think there is one thing which has come out of the war that is most important from the standpoint of research in industry, and that is the importance of having *samples*. Industry was able to turn over to war work and get production going in a short time because *samples* were available." Doctor Kettering pointed to the need for thorough understanding of the procedure of sample making as distinguished from the techniques of manufacturing or multiple production. He said that the process of making "samples" is akin to the creative art of writing a book or of composing music and that the process of manufacturing corresponds to printing books or to making phonograph records. Without too much regard for technical distinctions among the various phases of research, let us think of research as all of the processes involved in the development of "samples" from which industry can make unlimited copies to meet the unlimited needs of the people of the world. So much for our definition of research.

Freedom of opportunity, inherent in the makings of the United States has fostered research and invention. Research methods which through industry have provided us with the highest material living standard of any country in the world, conserved our resources, and helped insure our national future, should be applied equally to the fields of political economy and jurisprudence, urges this author.

Now let us take a look at "free enterprise," which, incidentally, is not included among the much-discussed, "Four Freedoms." Modern politicians use a very effective technique, which involves the selection and frequent repetition of words and phrases that do not necessarily create logical or even truthful impressions but have profound emotional effects upon the people who hear and repeat them.

"Freedom from want and fear" have strong emotional appeal. But these are not fundamental freedoms; they are objective and secondary. We cannot be endowed with them; we can only strive to attain them. Without fears and wants mankind would degenerate and perish. Such facts, however, do not diminish the emotional appeal of "freedom from want and fear."

There does seem to be one fundamental freedom which we gropingly attempt to define. It is not mentioned among the four freedoms. We hear a great deal about "free enterprise," but a recent Gallup poll indicates that only three out of ten people have a clear conception of what is meant by it. Perhaps there is a better expression for that fundamental intangible freedom for which we are presumably fighting the greatest of all wars. Among the answers to the Gallup poll, one of the best came from a truck driver in Oklahoma. He said: "It means a hell of a lot to me. I don't believe in this stuff of telling a man what he can and can't do." The same thought was expressed years ago in more scholarly language by the late great Supreme Court Justice Brandeis when he said: "The makers of the Constitution . . . sought to protect Americans in their beliefs, their thoughts, their emotions, and their sensations. They conferred, as against the Government, the right to be let alone . . . the most comprehensive of rights and the right most valued by civilized man." Patrick Henry defined freedom in no limited sense when he said so simply and so dramatically: "Give me liberty or give me death."

Another definition for this intangible, fundamental freedom is that it is the right of free men to work where and when and for whom they please, without restriction or penalty, so long as employer and employee agree, and the right to conduct a business as one sees fit so long as the operation of that business is not in conflict with the public interest. In brief, this freedom for which we are fighting this greatest of all wars—the freedom that brought supremacy to our country—this fifth freedom—is *freedom of opportunity*. I believe it is that inclusive fundamental freedom which we inadequately describe as "free enterprise."

INFLUENCE OF BASIC FREEDOM ON RESEARCH

Freedom of opportunity was inherent in the genesis of the American Republic, which brought about conditions almost miraculously favorable to conception, gestation, and birth of invention. The founding fathers freed their countrymen from restrictive influences, bestowed upon them compelling incentives, and created an environment conducive to effective co-operation on the part of all elements in a complex society. Moreover, the American Revolution and the adoption of our Constitution were almost exactly coincident with the great inventions that gave birth to the Industrial Revolution. Among other great incentives for research and invention, the Constitution of the United States provides that Congress shall have the power "to promote the progress of science and the useful arts. . . ." The first act of Congress, passed April 10, 1790, placed the granting of patents. Thomas Jefferson, as Secretary of State, personally examined many petitions for patents. For many years patents were signed by the Presidents of the United States.

Essential substance of an address presented at the winter meeting of the Industrial Research Institute in Rye, N. Y., January 28, 1944.

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Such blessings of opportunity and incentive were conferred upon an ingenious, restless, resourceful people, and research, in the inclusive sense of our definition, grew apace. Inventions increased in geometric ratio. Productivity per unit of man power was in consequence multiplied. The American mass market developed ever increasing buying capacity through widespread distribution of the fruits of increased productive efficiency among consumers, workmen, and investors. Profits and savings were reinvested freely to expand business and to exploit new inventions. Demand was stimulated and directed by increasingly effective salesmanship and advertising. In consequence of such cumulative and co-operating forces, the average citizen of the United States for many years has enjoyed the highest material living standards of any citizen of any country at any time in the world's history.

THE PROVING GROUND OF WAR

In the terribly tense days that followed immediately after Pearl Harbor a distinguished economist of German birth and international outlook made this prediction: "History will record the achievement of American industry as the outstanding miracle of the war." Evidence since accumulated has proved conclusively the soundness of Doctor Stolper's assertion. After ten years of political meddling, restriction, and persecution of American business and without adequate prewar preparation, our country now is producing war materials unmatched in quantity and quality by those that the German war machine is manufacturing after years of preparation and the application of the utmost effort of enslaved countries and individuals.

American research had grown prodigiously in the interval between the 1914 and 1939 phases of the World War. It is said that between 1920 and 1940 American industrial-research laboratories increased from about 300 to more than 2,200, and the number of American research workers from 7,600 to over 70,000.[1] Moreover, the most effective organizational procedure, in traditional American pattern, has brought the fruits of research into immediate and effective war use. The National Defense Research Council, the National Academy of Science, the National Research Council, the National Inventors Council, the several engineering societies, and—under the War Production Board—the Offices of Scientific Research and Development and of Production Research and Development, all have contributed directly toward the accomplishment of the "miracle" which Doctor Stolper predicted in late 1941. The very recent award by the Ordnance Department to the Society of Automotive Engineers is indicative of close association and effective collaboration between Governmental departments and scientific and technical societies.

Yes, we had the "samples" when we were confronted suddenly with the tremendous problem of converting America's scientific and industrial machinery from purposes of construction and the satisfaction of human needs to those of destruction, and we had a century and a half of intensive experience in acquiring the know-how of both research and production. We are beneficiaries of rich contributions given to our culture by the Eli Whitneys, the Robert Fultons, the Samuel Morses, the Alexander Graham Bells, the Cyrus McCormicks, the duPonts, the Westinghouses, the Edisons, the Pupins, the Henry Fords, the Coolidges, the Langmuirs, the Millikans, the Ketterings, and thousands of their spiritual kinfolk. Ingenuity, versatility, and adaptability are important elements in our rich heritage of freedom of opportunity. The "samples" that were available to us for war purposes were not simply "samples" of airplanes and tanks and guns and munitions. There were "samples" of machine tools, dies, jigs and fixtures, techniques of processing, and tool design—innumerable "samples" available from the great storehouses of knowledge and technique that have been filled by chemists, biologists, physicists, and technicians from thousands of laboratories and factories during the century and a half of our national existence.

Conder C. Henry, Assistant Commissioner of Patents, said:

> "It is a matter for national thanksgiving that we not only had available a vast storehouse of knowledge as represented by the 2,275,079 patents which had been granted prior to Pearl Harbor, but also that our citizenry have been trained and are accustomed to invent."

THE BENEFICIARIES OF RESEARCH

Our industrial heritage, stemming from and nurtured by research, is serving our country well in its hour of greatest peril. That fact is immediate and dramatic. For many decades research has been making vitally important contributions to the American standard of living. In the long view that fact, although less dramatic than our march toward victory, is more significant in its implications for the future. It is significant that those industries which have engaged in extensive research are the ones that have made the most generous contributions to the public good and incidentally to the welfare of their own employees and stockholders. There should be more general understanding that research benefits the people of the nation and of the world in far greater degree than it benefits the scientist or the inventer. It should be understood, moreover, that the business institution that multiplies and transmits the "sample" developed by research serves principally as a mechanism of transmission between the inventer and the people and is a beneficiary of research only in a secondary sense.

Michael Pupin's autobiography, "From Immigrant to Inventor," is one of the most inspiring books I have ever read. Among his many important inventions was that of applying inductance to telephone circuits, which completely revolutionized the art of telephony. In commenting upon the value of that invention, Doctor Pupin said:

> "A vice-president of the American Telephone and Telegraph Company, who is a very high authority in telephony, informed me recently that one way to describe, roughly, the value of the invention is as follows: If during the past twenty-two years his company had been compelled to extend its network of conductors so as to give, 'without employing my invention, the same service which it is giving today, it would have had to spend at least one hundred million dollars more than it has actually expended.' But after quoting him I wish to call attention to a fact which the public often overlooks. I ask, where are those one hundred million dollars which the invention has saved? I know that not even a microscopic part of them is in the pockets of the inventor. I have figured out also, with the same accuracy with which I once figured out the invention, that those hundred million dollars are not in the pockets of the telephone company. They must be, therefore, in the pockets of the American public. The invention made it possible to give the

telephone service, which is now being given, at a lower rate than would have been possible if one hundred million dollars more had been spent. *Every good invention benefits the public immeasurably more than it benefits the inventor or the corporation which exploits the invention.* I certainly consider myself a public benefactor, and the National Institute of Social Sciences called me so when it gave me a gold medal almost as big as the full moon. But this gift would have made me much more happy if the Institute had at the same time given another gold medal to the American Telephone and Telegraph Company."

William D. Coolidge, General Electric Company's director of research, recently made the following comment:

"It is not often possible to evaluate in dollars the benefit to the public from industrial research, but this lamp development lends itself to suggestive figures. It can be shown that, if the American public had had to produce with the lamps of 1900 the amount of light it actually used in 1942, the increased cost would have been approximately $4,000,000,000. Of course the public would not have spent that huge sum for light, but how great would have been the cost of inferior lighting in reduced safety and efficiency in our war industries and in reduced comfort and convenience in our homes cannot be estimated. Neither can we estimate how far below its present magnitude and efficiency would have been the electrical industry."

Economists generally agree that the automobile industry has been one of this country's greatest creators of wealth. It has set in motion other great industries—road building, the petroleum industry with its many ramifications, the great rubber industry—to name but a few. It has contributed importantly to the tax industry. It has been estimated that in the '20's the automobile and associated industries gave employment to ten per cent of our working population. Intensive research has been characteristic of this modern group of American industries. An uninterrupted stream of inventions and results of research constantly has energized and renewed these industries.

A little more than 30 years ago Kettering contributed the electric starter. At that time the automobile industry was simply an interesting infant. Women did not drive cars. There were no concrete roads nor low-priced closed bodies. The wealthy few who owned automobiles stored them during the winter months. The electric starter gave the industry tremendous stimulation. It multiplied the number of potential owners and drivers. Instead of being a facility available only to strong and venturesome men, the automobile became tractable in the hands of women and children.

There followed rapid development of our great system of concrete roads, filling stations and service depots, low-priced closed bodies, constant increase in volume of production with miraculous reductions in price, remarkable improvements in tires. In 1910 a good automobile tire would give about 2,500 miles of road service and cost $25. Now a tire of the same size, but containing more rubber and capable of being driven at much higher speeds, usually gives between 15,000 and 30,000 miles of service and costs initially only half as much as its 1910 predecessor. Synthetic rubber now promises to supersede natural rubber and to establish new high standards of service.

Then came other revolutionary changes. Gone were the old multiple coats of slow-drying paint and varnish before the advances of modern lacquer finishes. From the newly established General Motors Company research laboratories came Kettering's and Midgley's discovery of ethyl gasoline. From the laboratories of petroleum companies came new processes which led to more economical production of greater quantities of gasoline from each barrel of crude oil. Cracking stills became a reality. The new processes produced better fuels at lower costs. Such results flow from research, and we are only in the beginning.

One gains perspective as he considers the following statement made by Dr. Robert E. Burk, of the chemical-research department of the Standard Oil Company of Ohio:

"While speaking of gasoline, I should like to say something on cracking and antiknocks. The work of William Burton and others on oil cracking and of the General Motors research staff and others on anti-knocks, has resulted in an average increase of some ten per cent in the power derived from a gallon of motor fuel at the present time and has about doubled the yield of gasoline from crude oil. This amounts to a gain of roughly a billion horsepower in this country alone. Now it seems that there is a remarkable river named the Tennessee which runs through Tennessee but drains all 48 states, a power which is derived from a body known as the Tennessee Valley Authority. Without attempting to weigh the price against the glory of this authority, I have added up the approximate horsepower in the contemplated electric installations of all the TVA dams, that is, Wilson Dam, Norris Dam, Wheeler Dam, Pickwick Landing Dam, Gunterville Dam, and Chickamauga Dam, and the sum of all these monuments is about 715,400 horsepower. This is less than one tenth of one per cent of the horsepower gained from the anti-knock and cracking research. Moreover, I have never heard a single politician eulogize William Burton or the General Motors Corporation for their work in conservation. In any case, we shall plainly be dammed in a big way if politicians try to equal the power-conservation feats of the chemist by building the thousand odd TVA's which would be necessary."

Rapid developments in ferrous and nonferrous metallurgy have attended the evolution of the motorcar industry. Modern alloy steels have contributed to improved structures, reduced weights, increased power, and lower costs. The metallurgy of cutting edges has multiplied production and has contributed to revolutionary improvements in machine tools.

The motorcar industry has helped to bring many new industries into existence, and also has caused the output of many older industries to be multiplied. The list includes, among many others, iron and steel, fibers and fabrics, plate glass and plastics.

Examples of the great contributions that have been made to the people of the world through research by industry could be recounted endlessly. Developments in commercial chemicals and dyes in the past 25 years have been prodigious. Great new industries have grown from research devoted to synthetic fibers—rayon and nylon. Volumes have been written about research in plastics and their commercial possibilities.

Research in the fields of radio and electronics already is bringing about revolutionary changes in our lives and has contributed vitally important instruments to our prosecution of the war. David Sarnoff, president of Radio Corporation of America, said in a recent address:

"It is radio which has made possible a war of speed and mobility on land, at sea, and in the air. Bombers fly to their targets and return to their bases with the aid of new radio devices. Radio-electronic sentinels stand watch on shipboard and along the coast. Infantry, artillery, and tank units co-ordinate their movements by radio. The United States now has fighting forces stationed at

more than 60 strategic locations on the world map. Its Navy operates on the Seven Seas. Without instant reliable radio communication it would be impossible for these widespread forces to function as a unified war machine."

He spoke of the great new areas opened to science by the electron microscope with its range of 100,000 diameters, the spectacular new industrial processes which stem from applications of electron tubes, and nationwide television as an early postwar probability. He concluded by saying:

"I have mentioned only a few of the promises of the future. There are many more. In each of them, science has written a promissory note, payable when the war is ended in terms of a fascinating new civilization in which life will be easier and more abundant, transportation swifter and more comfortable, and communication by sound and sight a universal convenience."

Research is an important means of conserving our resources and insuring the future of America. F. Russell Bichowsky, research engineer, says in the preface to his booklet, "Industrial Research:"

"There are no new lands for America to exploit. It is probable that there are but few new mines and oil deposits yet to discover. There is left but one possible source of new wealth to replace the wealth lost in war. This source of wealth is the discovery of new products to manufacture and sell. It is on this source of wealth that we must depend now and in the future for the means to maintain and raise our standards of living.

"It is from the research laboratory that this new wealth must arise, as has originated in the past the new wealth represented by the automobile industry; the radio industry; and the industries founded on the movies, the electric lamp, the aeroplane, plastics, rayon, nylon, Kodak, and hundreds of other new products. This wealth has never been fairly estimated but it probably represents well over two hundred billion dollars."

Equally entrancing vistas are opened to our view when we hear physicists, electrical scientists, chemists, medical-research men, refrigeration and air-conditioning researchers tell of the things that lie ahead. During the quarter century just passed, research has brought important new means of refrigeration to the people of the world, and, as usual, people of the United States have been the major beneficiaries. For a long time we have taken abundant food supply as a matter of course—something like the air we breathe—that just happens. Reports of famine in far countries have left us almost untouched. Only recently have we heard of "food shortages" and "food rationing;" of these matters we shall hear far more in the months to come. New importance now attaches to food production, food preservation, food preparation.

In this country more than 17,000,000 gas and electric automatic refrigerators, installed in American homes, conserve our food supplies. This great battery of food preservers is augmented by great cold-storage warehouses, by refrigerated freight cars, and by refrigerated ships, by frozen food lockers and by commercial plants for processing frozen foods. As we look forward to the postwar days we realize that this art of controlling temperatures at subnormal levels is only in its beginning, and that new conveniences and new means of conservation will help to give increased employment to the workers of America and new services to American homes.

Air conditioning is only in its swaddling clothes; future homes, particularly in our own blessed land, will be maintained at constant comfort levels through out the year. Summer air conditioning will be no more unusual than central heating and modern plumbing. Already our engineers have installed residential all-year air-conditioning plants from the Atlantic to the Pacific and New England to New Orleans. These plants bring about both summer cooling and winter heating from the same gas flame. Only the removal of war's restrictions is required to make such plants as readily available as modern gas-heating plants.

Aircraft technology has reached a tempo without precedent under war pressures. To visualize the revolutionary effect of air transport one need only read editorial and advertising matter in our current magazines. That our minds fail to grasp the third-dimensional implications that characterize air transportation, is made clear when one studies current controversies about "freedom of the air."

Yes, warfare forces technology to adopt a faster pace. After World War I many existing industries were greatly accelerated, and great new industries came into existence. When the curtains which now, of necessity, conceal the work being done in our research laboratories, are withdrawn, many essential "samples" for developing new industries and accelerating older industries will be disclosed.

Can "we, the people" insure a favorable environment for the full development and the maximum duplication of these "samples?" We can if we will, but rigorous thinking and decisive action are needed—not tomorrow—but today. "It is later than we think."

RESEARCH METHODS IN POLITICAL ECONOMY

A profound and terribly disquieting change has taken place. Our people are increasingly willing to exchange freedom of opportunity for empty promises of security. So far this country has been too strong and too rich to be overthrown by revolutionary socialism. Nevertheless, we *are* the victims of insidious, encroaching socialism. We may as well face that fact and the corollary fact that, in the degree to which socialism, paternalistic government, and dictatorship advance, freedom of opportunity diminishes.

As we consider the current scene, we must avoid confusing symptoms with the underlying disease. Corruption of the courts, the ascendancy of demagogues and crackpots, the expansion of bureaucracy with its vagaries and stupidities, dictatorship are among the *symptoms* of national decadence. The psychological basis of our retrogression is clearly analyzed and projected by Henry C. Link in "The Rediscovery of Man:" "After centuries of painful progress toward freedom and democracy, the world is rapidly moving back into social slavery . . . Such slavery does not just happen. It must be deserved . . . In the United States, which is moving in the same general direction, we can still observe the process by which the people are being prepared."

In a book, entitled "Human Engineering or the Manhood of Humanity," written by Korzybski some years ago, it was pointed out that, whereas some human activities are based upon scientific method and thinking—"rigorous thinking" Korzybski called it—many other human activities stem from unscientific traditional thinking, or "speculative philosophy."

Korzybski developed the theme that activities growing out of scientific thinking and method tend to advance geometrically, whereas activities based upon traditional

thinking, like political economy and jurisprudence, advance only in arithmetic ratio. From this hypothesis he developed the thought that lack of understanding and conflicts develop because the rapid advance of scientifically generated projects outdistances advances in traditional fields with a consequent strain upon the social structure. Having learned to apply the methods of scientific research successfully in so many fields of human endeavor, why should we not use similar methods to accelerate advancement in other fields equally important to human welfare?

What of taxation, for example? Someone recently said that if one of Hitler's cleverest agents had devised the Federal taxes of the United States solely for the purpose of accomplishing Hitler's aims he could have done nothing more effective than has already been done by our own legislators.

In the spring of 1939 I had the privilege of addressing the Congressional delegation from Indiana on the subject of "Business Taxes," and I presented this thought, which wes not new. I quote from the *Congressional Record:*

"A final suggestion for long-range planning is made which may be too idealistic for realization. Would it not be a measure of constructive statesmanship to place tax planning and specific recommendations in tax matters to the Congress within the control of a well qualified permanent nonpartisan board, which would approach our present confused inefficient self-defeating aggregation of tax measures with an objective long-range constructive viewpoint, calculated gradually to bring order out of chaos and to develop a carefully correlated tax program, scientifically planned to produce maximum revenue and to avoid undue restriction of those activities which are essential to develop increasing national income?"

In the third supplement to *Fortune* of December 1942, the following significant comments on taxes are found:

"In the final analysis, it is the elusive giant, confidence, that chiefly influences, if it does not control, the birth rate and expansion rate of business . . . No policy is potentially more dangerous for economic life or death than taxation."

Then follows this suggestion:

"But when the first big postwar tax bills are written, piecemeal reforms will not suffice to serve the needs of an expanding economy. What will be needed is a complete and uninhibited overhaul of the whole structure, starting from the basic question of what a federal tax system is for. To this end a nonpartisan commission of experts, both government and private, should be set up, along the lines of a British Royal Commission or our own Baruch Rubber Committee. Its personnel should command general confidence, so that its report and recommendations will have weight with Congress. It should start with the assumption that we have no federal tax system at all, and then lay down the lines along which a good one must be drawn. In addition, as proposed in a resolution offered by Representative Coffee (Washington), the Commission should study state and local tax systems, seeking ways to integrate all three."

The importance of such procedure with respect to taxes, which at best must continue for many years at extremely high levels and which for that reason, if for no other, should be planned so as to produce *maximum revenues* with the least restrictive effect upon *tax sources*, is underlined by the vast confusion and delay that have attended recent deliberations and controversies in tax matters between the Congress and the Administration.

In the less complex but much debated field of patent practices, President Roosevelt has established a healthy precedent which may have far-reaching effect in our political economy. A distinguished "nonpartisan group of experts, both Government and private," was organized in 1941. The National Patent Planning Commission is headed by Charles F. Kettering, and includes Chester Davis, president of the Federal Reserve Bank of St. Louis; Francis P. Gaines, president of Washington and Lee University; Edward F. Grady, consultant to the Undersecretary of War; and Owen D. Young of the General Electric Company. A. A. Potter, dean of engineering, Purdue University, is executive director of the Commission. The Commission, in conjunction with the Department of Commerce, is authorized to "conduct a comprehensive survey and study of the American patent system and consider whether the system now provides the maximum service in stimulating the inventive genius of our people in evolving inventions and in furthering their prompt utilization for the public good." Here, indeed, is a group to "command general confidence, so that its report and recommendations will have weight with Congress."

The Commission's first report was made last June. After face-to-face discussion of its recommendations by the Commission with President Roosevelt, legislation was prepared embodying the Commission's recommendations. In contrast to the political persiflage presented to the Senate patent committee by various "speculative philosophers" is the Commission's recommendation that "It would not be advantageous to incorporate compulsory licensing in our patent laws." Without equivocation the Commission's report states that "The strongest industrial nations have the most effective patent systems, and, after careful consideration, the Commission has reached the conclusion that the American system is the best in the world."

The National Patent Planning Commission is an encouraging example of application of the scientific method to affairs of government. The method of approach used and the recommendations made by this Commission afford a startling contrast to the provisions of the Kilgore Bill, which is symptomatic of the worst tendencies of our times. The Patent Commission is quite conscious of the profound and beneficial influence of the existing American patent system upon our national welfare, proposes to retain its body of sound precepts and practices, and suggests legislation which will remedy its deficiencies and increase its scope of service. Proponents of the Kilgore Bill, at the other extreme, disregard all historical facts with respect to research and patents; set forth certain untrue and indefensible promises; and propose socialization, elaborate bureaucratic control, and destruction of existing incentives with respect to research and patents.

Walter Landis, vice president of the American Cyanamid Company, discusses the Kilgore Bill and its implications at length in a well-documented brochure dated October 15, 1943. Vannevar Bush's letter to Senator Kilgore,[2] and Frank B. Jewett's address, "The Promise of Technology,"[3] also deal with this subject.

Liquidating billions of dollars worth of war contracts quickly and equitably to the end that reconversion of and re-employment by an expanding peacetime industry may not be delayed unduly is another important task for a well-qualified commission. Restoring the flow of capital which long ago ceased to be available in sufficient volume to provide for an expanding economy is another problem which must be solved if America is to continue its forward march toward full-employment and an economy of plenty.

Here also is an opportunity to use the nonpartisan fact-finding technique applied by men whose abilities and reputations are above question. The research division of the Committee for Economic Development may be expected to contribute to the solution of these and kindred problems of magnitude beyond all earlier experience, but of importance so vital that we dare not delay aggressive and comprehensive approach to their solutions.

The Administration has established significant precedents in the Baruch Committee report on rubber and in the Patent Planning Commission. Business leadership is using sound research techniques in the operations of the Committee for Economic Development, and in those of many other groups who recognize and propose to deal realistically with postwar problems. All thinking people of the United States must support the application of the research method to vitally important problems where scientific approach heretofore has been notably lacking.

QUO VADIS?

The people of the United States have received incalculable material benefits from research which is indigenous to the fertile soil of American free enterprise. Our generation now witnesses the dangerous erosion of that soil and rapid depletion of its fertility. To win this greatest of all wars after paying the hideous price in terms of life, human wreckage, natural resources, and other forms of material wealth and then to lose the fundamental freedom of opportunity would be a terrible tragedy. The human race, despite its consistently suicidal proclivities so far has been preserved by the operation of immutable laws which were established in the beginning by the Designer of the Universe. If such laws were amenable to modification or repeal, our remote ancestors would have "perished from the earth" long before Americans engaged in experimentation with "government of the people, by the people, for the people."

The tragic loss of fundamental freedom may be postponed by the operation of the immutable law of action and reaction, but the nation can be made permanently safe only by the redirected effective education of its people in the fundamental ideals upon which our culture has been built. As a reunited people we must experience a rebirth of the integrity, the moral and spiritual values, and the willingness to participate in government that inspired and animated the founding fathers.

"It is later than we think."

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Radio in Aviation

CHARLES I. STANTON

A pioneer in the application of radio to aviation and long closely concerned with radio as a factor in building and operating airways in the United States, the author reviews the latest applications of radio to the operation of commercial air lines in this article, and predicts a great need for low-cost radio equipment in the many privately operated airplanes that may be expected in postwar years.

RADIO and communications occupy an increasingly important role in all considerations of postwar flying problems. The development of low-cost aircraft radio equipment is vital to the growth of private flying, but radio and communications are particularly crucial to commercial aviation. In fact, satisfactory control of the increased commercial traffic expected after the war will be impossible without improved radio and communications equipment. The alternative would seem to be to reschedule air-carrier traffic in the interest of safety, and, indeed, this has been done to a limited extent at times.

The magnitude of this problem can be appreciated when it is realized that aircraft movements handled by Civil Aeronautics Administration traffic-control centers increased from about 25,000 a month in 1938 to more than a million a month in 1943, a 40-fold increase in five years. Part of this increase resulted from the creation of 15 additional control centers, but with 23 now in operation the United States is believed to be divided into the smallest areas practicable for handling traffic which moves, usually, at about 180 miles an hour. Nevertheless, every indication points to a further increase. This increase was foreseen during the years just before the war, and several steps were initiated to take care of it, but war-dictated priorities halted action on many of the plans.

Essential substance of an address presented before the communication group of the AIEE New York Section at a joint meeting of the Section and the New York section of the Institute of Radio Engineers in New York, N. Y., February 24, 1944.

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IMPROVEMENTS IN RADIO RANGES

In 1941 there was begun what was intended to be a five-year program for shifting radio ranges over to ultra-high frequency. The principal limitations upon the use of the present type of range are: crowded condition of the 200- to 400-kilocycle frequency band; susceptibility of the stations operating on frequencies in this band to interference over long distances; night effect or signal distortions resulting from reflections from the ionosphere; vagaries resulting from distortion of the radiation pattern by the effect of irregular terrain; high degree of interference from atmospheric static; and precipitation static.

Present radio-range frequency assignments are spaced only three kilocycles apart, and it is necessary to operate a number of stations on each available frequency, relying upon geographical separation to limit interference. A saturation point has already been reached, and few if any low frequencies are available for future expansion of the range system.

To overcome the limitations of the low-frequency ranges and provide for future expansion of the airways system, the CAA for several years has been engaged in the development of an ultrahigh-frequency radio range to operate in the frequency band from 119 to 126 megacycles. At these frequencies, interference from atmospheric and precipitation static is practically nonexistent, and interference between stations on the same frequency will not occur, at practical flying altitudes, provided their geographical separation is 200 miles or more.

The ultrahigh-frequency range developed by the CAA operates on a somewhat different principle from the low-frequency ranges, and provides one pair of courses indicated visually in the aircraft by a zero-center left-right indicator; and another pair of courses at right angles to the visual courses, which are indicated by interlocked keying of the Morse code characters D and U (dah dit dit and dit dit dah, respectively) with 1,020-cycle audio tone modulation.

The antenna system of the ultrahigh-frequency range is in general similar to that of the low-frequency range except that its physical size is very much smaller while the electrical spacing of the radiating elements in terms of the operating wave length is very much greater. The five radiating elements may be either horizontal loops or vertical rods, depending upon whether horizontal or vertical polarization is desired. One pair of diagonally opposite corner radiators and the center radiator constitute a complete two-course range antenna, so that the two pairs of diagonally opposite radiators form two two-course range antenna systems independent of each other except for the common center element. The antennas of the pair radiating the signals that register on the visual indicator are excited 180 degrees out of phase by side-band energy arising from modulation of the carrier frequency by 90 cycles and 150 cycles simultaneously, but from which the carrier frequency itself has been suppressed. The center element radiates the carrier frequency plus also 90-cycle and 150-cycle side bands. The side-band energy radiated from the center element combines vectorially with the radiation from the corner elements to produce a field pattern resembling two cardioids with axes extending in opposite directions along the line of radiators, and two points of intersection directly at right angles to the line of radiators. In one of these cardioid patterns the 90-cycle modulation predominates, in the other the 150-cycle modulation, while at the points of intersection both modulations are equal. Thus, the line of intersections defines a course with modulation at 90 cycles greater on the one side and with modulation at 150 cycles greater on the other side.

The other pair of radiators produces aural courses at right angles to the visual courses in exactly the same way, except that a single modulation-tone frequency, 1,020 cycles, is used and the courses are defined by keying a D (dah dit dit) into one cardioid and a U (dit dit dah) into the other. The center antenna common to both systems must radiate the carrier frequency and all of the side bands required to produce the desired directional patterns in combination with the radiation from the corner antennas.

The aircraft receiver for use with the ultrahigh-frequency range is of conventional design. It has two independent output circuits: one for the frequencies of 90 and 150 cycles which actuate the visual meter, and the other for the tone frequency and speech. The 90- and 150-cycle frequencies are separated by two band-pass filters. The outputs of the filter sections are rectified, and the resulting direct voltages are applied in opposition to the zero-center meter so that it deflects to one side or the other depending upon whether the 90-cycle or 150-cycle signal is the stronger.

The two-course-aural and two-course-visual range system has a number of important advantages over the four-course aural range in addition to those already cited. In the four-course range, the same "off course" signal is heard in two opposite quadrants. When a pilot is completely lost and must rely upon a four-course range for orientation, it may be a tedious and time-consuming process to determine which of two quadrants he is in. The two-course-aural and the two-course-visual range, on the other hand, has no quadrant ambiguity, since its courses are formed by four unidirectional patterns rather than two bidirectional patterns. In this, too, the course indications are produced by varying modulation levels in the field about the station while the carrier itself is radiated in a circular pattern and does not vary with azimuth. It is thus possible to use automatic volume control in the aircraft receiver to eliminate or reduce fading and surges in the signal level over rough terrain without affecting the definition of the courses.

Ultrahigh frequency ranges were satisfactorily service tested on the Chicago–New York airway in 1941, but entry into war made it impossible to proceed with plans to convert the entire airways system. In fact, about 15 per cent of the ranges of the existing type had to be removed from domestic service and installed elsewhere for use of the military air forces. The range equipment at Evansville, Ind., for example, was relocated on Ascension Island, to guide fliers across the South Atlantic.

OTHER ULTRAHIGH-FREQUENCY APPLICATIONS

Ultrahigh frequencies will have other applications in the airway system. Airport traffic-control towers will operate in this band, as will the instrument landing systems at airports.

The CAA, in co-operation with the War Department, is installing at more than 100 airports ultrahigh-frequency radio transmitting equipment designed to permit properly equipped aircraft to make instrument approaches in very low ceilings and visibilities—or even landings in conditions of zero ceiling and visibility. At present, only military aircraft are so equipped.

A complete instrument landing system consists essentially of four separate transmitting stations located on or near the airport. These four elements are known as (1) the localizer, (2) the glide path, (3) the boundary marker, and (4) the outer marker. A middle marker is being installed at some airports. Although any number of markers may be used, two are usually sufficient.

The localizer provides a very accurate lateral guidance so that approaching aircraft can maintain a heading that will lead them over the center of the runway. The glide

path provides vertical guidance enabling the aircraft to maintain the proper rate of descent. The markers provide reference points or "fixes" along the approach paths, which permit pilots to verify their positions and altitudes.

No glide path is included in current installations because equipment is not available, but equipment is expected to be installed as soon as it is available.

Use of the localizer and markers alone permits instrument approaches under weather conditions much less favorable than those now required. Thus, approaches to an airport with 100-foot ceiling and one-fourth-mile visibility will become feasible, whereas present minimums are 400-foot ceiling and one-mile visibility.

The localizer is basically a two-course radio range operating at ultrahigh frequencies. A linear array of horizontal loops is placed at right angles to the axis of the runway and radiates what amounts to two space patterns. These patterns represent modulation of the same carrier at 90 cycles and at 150 cycles. The signals are rectified and separated in the aircraft receiver, and the two resulting direct voltages are applied to a right-left indicator which indicates the difference between these voltages. The two patterns cross only at the two points where the two signals are equal in amplitude.

Along these two directions, which are 180 degrees apart, the indicator shows zero or "on-course." Along any other direction the amplitudes of the patterns are different and the needle moves to the right or left, depending upon which of the two signals predominates. The rate at which the ratio of the amplitudes of the two patterns departs from unity, as the azimuth changes from "on-course," determines the so-called "sharpness" of the course.

The aircraft receiving apparatus consists of a small marker receiver and a localizer receiver. The output of the former is fed into three filters, each of which controls a pilot light. Thus, if the modulation happens to be 400 cycles the corresponding filter functions to close the power circuit to its pilot light. By this means the pilot knows which marker is being received.

To receive the horizontally polarized localizer signal, either a horizontal loop or a horizontal receiving antenna is placed on the airplane above the fuselage. The latter is a pair of elements approximately one-fourth wave length long, grounded at the junction point. The line is tapped on either side of this junction to obtain an approximate match of impedances.

AIR TRAFFIC CONTROL

Ultrahigh-frequency radio ranges, airport-control-tower communications, and instrument landing systems are only a part of the answer to postwar traffic increases. Air traffic control already has been discussed in a previous article (*EE, April '44, pp. 119–25*).

One bottleneck in the air-traffic-control system is the means of posting flight information at the centers. At present, data concerning the progress of each plane are written on slips of paper and placed in slots on a board, an entirely manual operation. It is slow at best, and when traffic is heavy, the job of posting the slips causes the board to be obscured too large a portion of the time.

Introduction at the earliest possible moment of electrically operated boards, on which flight data are posted automatically, is proposed. This plan has been tried successfully at Washington National Airport and will be installed in the busiest centers as soon as funds are made available and the equipment produced.

Although there has been a forced wait for improved equipment, the war has not slowed down attempts to improve procedures. Approach control is one of the more important innovations being developed. Up to now it has been customary for a plane approaching an airport to maintain contact with the control tower only indirectly, through an airline or military radio station, becoming subject to airport-tower control only when it came in sight of the field. Under the approach control system, the controller takes over when the plane comes within 15 miles. This makes possible landings only 5 minutes apart in instrument-approach weather, as compared with 15-minute separation under conventional methods. This system is in operation at Atlanta, Ga., Kansas City, Mo., and San Diego, Calif., and is being extended as rapidly as possible, subject to the approval of the chief users of each airport.

PRIVATE PLANES FOR POSTWAR FLYING

Thus far radio and communications have been discussed primarily as they affect commercial air transportation. Today, of course, commercial and military planes are the chief users of these facilities. In the postwar decade, however, there may be as many as 500,000 civil airplanes in the United States, most of them privately owned; it is inevitable that many of these will be equipped with radio.

First, the private flier will want radio to make his flying simpler and safer. The radio compass, which makes it possible for a plane to fly straight toward the station to which it is tuned, will probably be standard factory equipment, except on the lowest-priced planes and on training planes that stay near the airports on which they are based. Experienced pilots all know how easy it is for beginners to get lost in the air, and radio can be the most valuable of all flying aids, both to the new as well as the veteran pilot.

Perhaps most important, the private flier will need and demand radio for his use in obtaining weather information. There can be no safety in widespread private flying without rapid transmission of weather information to planes in flight. Hence the private owner's radio equipment probably will be a receiver operating on ultrahigh frequencies, with a direction-finding attachment. In quantity production, such equipment should sell for a modest price. At least one company is prepared to produce the receiver alone for less than $30. For communication, many private owners will want a transmitter operating on a high frequency for communication with airport towers and CAA stations. This transmitter should cost not more than $50 on a mass-production basis, and a complete installation might cost $150 on the same basis.

This article has been confined to the radio and electrical developments in prospect for aviation during the immediate future. These, of course, are mild in comparison to what may be expected when the electronic devices being used in this war are adapted to peace-time needs. But that will involve a long-range program of development, and will not, as many laymen believe, happen overnight. The CAA hopes to work on this, in co-operation with the research departments of private industry and universities, as soon as war conditions permit. In the meantime, however, effort is being concentrated on solving today's problems with today's means.

Electrical Engineering in the Postwar World

II—Position of the Engineer

EVERETT S. LEE
FELLOW AIEE

TODAY the engineer is working under enormous pressure due to the keenness of the competition of the war, competition the like of which there has never been before. The war production is everywhere requiring his services. As he solves urgent needs, newer needs come into being for solution. On the day the war ends, the engineer will be on the firing line of engineering contribution for war. And the day after the war ends, he will be on the firing line of engineering contribution for peace.

One thing is certain in the postwar world—the engineer will continue in his present role to unearth new knowledge and to produce new things. And by engineer, I mean scientist and engineer. Also, the engineer will continue in his present role to improve present things. These characteristics define the engineer.

Everything we have comes to us from the engineer. This paper from which you are reading, the press on which it was printed, the transportation which brought it, all came to us from the engineer. The house in which you are, the furnishings, the lights, the street outside, the bridges, the tunnels, the buildings of the city, the telephones, the telegraph, the movies, have all come to us from the engineer. The farm equipment on the farms, the roads, the automobile, the radio, the airplane, electric power for the home, electric power for industry, the processes of industry, the metals from the mines, have all come to us from the engineer. The tanks, guns, planes, ships, and ammunition of our present war production have all been brought into being by the engineer.

This article, second in a series discussing the general subject, is devoted to determining the probable part the engineer will play in the postwar world. As in the past, the engineer is expected to expand and apply knowledge for the benefit of all. Beyond this, however, is the question of the control by the engineer of the uses to which his products may be put, in order to insure that they are used for good and not for evil. Because of his knowledge, professional position, and the strength of engineering societies, the engineer should take an active part in guidance toward a wholesome life.

The opportunities for all people to work have come to us from the engineer. The opportunities for all people to work in the future will come to us from the engineer.

The engineer works. He works to bring new things into existence. He works to bring into being the first of all of the things which we have. He works to fashion them into useful articles. He works together with all working men and women of the land. And he lives with them in appreciation of their contributions and his dependence upon them as they have dependence upon him.

At the same time, in his daily work, the engineer is an individualist. His workshop is nature. His stock in trade is nature's laws. His tools are the sciences. His output is the first one of new things. He gives guidance to the continued fashioning of things by millions and millions of other workers. In this he provides for all the jobs there are. He lives in a world of scientific freedom limited only by his ability. He serves with other engineers, often times with many, yet he retains his individualism in engineering contribution.

This is the engineer as he has been, is, and will be. Recently newspapers published the account of the death of Leo Hendrick Baekeland, chemist and chemical engineer. He invented Velox in 1899; picture to yourself the extent of the photographic industry into the manifold walks of life. He invented bakelite in 1906; today plastics is still a magic word as it includes items by the thousands "from billiard balls, fountain pens, umbrella handles, buttons and pipe stems to airplane propellers, automobile self-starters, telephone receivers, and switchboards and insulation for battleships." (New York *Herald Tribune*, February 24, 1944). Or recall the engineering contributions of Edison, of Steinmetz, of Westinghouse, of Goethals, of Hammond, of McNaughton, and of a host of others that you know, and if the complete record of all engineers could be written, it would be a record of services rendered to their fellowmen by thousands and thousands and thousands of engineers, all to the end

An address presented at a conference on "The Engineer in the Postwar World" on March 4, 1944, in New York, N. Y., under sponsorship of the Research Bureau for Postwar Economics and its co-operating institutions.

Everett S. Lee is engineer, general engineering laboratory, General Electric Company, Schenectady, N. Y., and is currently chairman of Engineers' Council for Professional Development.

that all men would have available for their use the manifold wonders of nature.

SIGNIFICANT CONTRIBUTIONS OF ENGINEERING

Most significant to our way of life has been the providence of the fruition of engineering contributions in these latter days. When a reflected radio signal was first observed in the United States Naval Research Laboratory some years ago, engineering and scientific skill, ability, perseverance, and hard work put together with engineering ability in other fields enabled the British later to put up a protective curtain to keep the enemy from Britain after he had overrun France, producing a power which preserved the very principles which were its foundation. May there be a recognition of this fact.

Or, when several years ago Russia came to American industry to obtain American engineering understanding and technique, the engineering books of industry were opened to the Russians, engineering knowledge was imparted, engineering know-how was provided in person in Russia by Hugh Cooper and many others, and today the result of that imparted and inspired engineering ability propelled by intense application, perseverance, and hard work by the Russians has built up again a power which has preserved the very principles which were its foundation. May there be a recognition of this fact.

Or, when Marvin Camras, young engineering student at the Armour Institute of Technology just a few years ago, brought to the science of recording sound on wire a new concept to give greater fidelity and which has since enabled information of the enemy to be recorded from the air for the services, here was a classic example of a young man on the firing line of engineering knowledge, giving of his ability to produce a new and useful result, typical of what is going on in the lives of thousands of our young engineers who are today contributing in their early years to engineering and scientific advance as no one else can do. In our young engineering manhood our future is secure that there will be continued contribution just as it always has been and just as it always will be. May there be a recognition of this fact.

The position of this young engineering manhood is being sacrificed however. War is ruthless. When the President of the United States called upon us all to make our country an arsenal of democracy, there was immediate action and we witnessed the acceleration into being of the greatest production output the world has known and in the shortest time. The basis of this was the engineer. As the engineer had permeated the production for peace, so he permeated the production for war. And the source of this engineering bulwark was the young engineers trained in the colleges of our land entering the profession each year at the increasing rate necessary to maintain the engineering output required by our country in time of peace. This annual inflow to American engineering talent, ability, and understanding had grown to 15,000 engineering graduates in each year. Today the number available to American engineering outside of the services is practically zero.

As the engineer faces this situation which has been forced upon him even as he pleaded against it, we can only trust that the sacrifice which has had to be made is recognized by those in high places that it will not have to be extended and that just as soon as possible the lost ground can be regained.

THE POSTWAR POSITION

The position of the engineer in the postwar world is secure as regards the fact that he will continue to produce. But the larger question is, what will the people do with the products of the engineer? What the engineer produces can be used for good or for evil. If he, fearing its use for evil, does not produce it, neither is it available for good. Thus he produces it, and the people who use it must learn to use it for good. The motives of the engineer are for good, for to use the laws of nature he must be honest and in using the laws of nature he just naturally is honest. And he expects honesty in the use of his products. And where there is not honesty, there will be travail.

As the engineer has worked he has associated himself with other engineers of his calling to build the professional engineering societies of the land—active, virile organizations of strength where together with his fellow engineers he may present to the world the record of what he has accomplished. And as these societies have grown in their individual strength, the profession has come into being. They are the profession.

In the engineering societies are engineers from every abode of engineering endeavor—from every industry in the land; from the large company; from the small company; from every utility; from the transportation systems of the country; from the schools and colleges; from government, municipal, state, national; from private practice; from the countries of the world; from everywhere.

And in these places of engineering accomplishment the engineer is found in every position. There are the young college graduates entering the profession to accept their initial responsibilities, the junior engineers active and progressive, the senior engineers of experience, the chief engineer, the president, the chairman of the board. In every place of life the engineer will be found, and his contribution to society thus goes beyond the technical into the administrative with broad responsibilities for human welfare. And these have been reflected in his professional society life.

There is the urge to make these even more prominent. Some 11 years ago there was founded the Engineers' Council for Professional Development to co-ordinate and promote efforts to attain high professional standards of education and practice, greater solidarity of the engineering profession, and greater effectiveness in dealing with technical, economic, and social problems. Much for good has been accomplished. There is still much to be done.

But by and large the engineer's contributions are to the technical, and from these there has resulted a massive monument of accomplishment; a foundation, structure, and superstructure of achievement; a wealth of things for the people to use. To this picture we return again and again; it is so prominent.

And as we consider it, we see most prominently displayed an equal picture as we look into the postwar world with all the peoples of the world producing and wanting and needing these things. What the engineer would accomplish in the solution of his problems beyond the technical, so the world would accomplish in keeping the peace for which so great a struggle is now in progress. The two are much the same, practically identical.

With all the planning of the present time for the postwar world, in whatever phase, there is recognition that where war is tangible in objective, peace is intangible in objective; therefore much more difficult to progress. But the underlying laws are easy—everybody knows them. Do unto others as ye would be done unto you: Love thy neighbor as thyself. Love thy God with all thy heart. These do and thou shalt live. Herein is the opportunity for a wholesome living. That is what each man wants. That is what each man shall have if we have peace.

But the ramifications are enormous, the complexities are intense, and in spite of all controls power becomes amassed and conflict follows.

To the end that the individual engineer may contribute in the place where he is, the Engineers' Council for Professional Development has issued the pamphlet "Will You Help?" This calls upon all members of the local chapters, sections, and branches of the participating bodies, together with other local engineering organizations and interested groups, to participate in the coordinated societies' endeavors. Where this will lead will depend upon the activity of the groups and the earnestness with which they enter into the problems which they find. But potentially there is an opportunity to bring into discussion and suggestion for solution any problem suggested. Here is an opportunity for a portion of the engineer's time to be given actively to the solution of those problems which he wants to be solved and which must be solved to maintain the wholesome life. That this is not entirely new we recognize; that there is infinitely more opportunity for great good, however, is clear. May the engineering profession see it clearly and progress it wisely.

The world today has plenty of opportunity to see and feel sacrifice. It is everywhere. And to what avail? That there will be brotherhood. To have brotherhood men must feel it, men must think it, men must act it. There must be a recognition of the love of God for man, of man for man, of man for God. Without this the position of the engineer in the postwar world will be insecure just as will be the position of his fellowmen. This is inescapable.

The engineer through his knowledge of nature's laws has the best of opportunity to contribute wise counsel. He knows that abundance must be paid for at great price. He knows there must be balances. He knows there must be safety factors. He knows you can't get something for nothing. He knows the havoc of uncontrolled power. He knows of the evil results of small squeaks.

Those and others the engineer can bring to the local discussion, and from the local to the national, and from the national to the international. It is most worthwhile.

And thus the engineer in the post-war world, continuing his contribution to the providing of things for the needs and welfare of the people, can bring to his locality and beyond the helpfulness of his understanding towards a wholesome life. The potentialities are enormous; the objectives make the effort worthy; the consequences of nonparticipation, which may even mean a recurrence of conflict, are just too serious to be allowed.

Overhead Welder Travels Assembly Line

This portable spot welder has halved the time and the number of operations necessary for assembling *B*-26 bomb-bay doors by the Glenn L. Martin Company. The skin, frames, and stiffeners for the doors are assembled in a fixture to be tack-welded with the portable spot welder and the entire assembly then is carried to a floor-type spot welder. The portable welder consists of a spot weld machine and transformer counterbalanced on a small beam pivoting from an overhead trolley which travels along a 50-foot I beam. The trolley is propelled by sprocket and chain powered by a one-third-horsepower electric motor. A 200-kva welding machine with a capacity of two thicknesses of 0.040-inch aluminum is used.

INSTITUTE ACTIVITIES

Summer Technical Meeting Program to Be Largest in the History of the Institute

The tentative program arranged for the AIEE summer technical meeting to be held in St. Louis, Mo., June 26–30, 1944, will be the largest technical program in the history of the Institute. This makes the meeting a fitting occasion to commemorate three important anniversaries in the electrical field—the 60th anniversary of the AIEE, the 100th anniversary of the Morse telegraph, and the 40th anniversary of the International Electrical Congress, which met in St. Louis in 1904. The program is comprised of approximately 89 technical papers and 31 conference papers to be presented in 28 technical sessions and conferences, in almost as many specialized fields of activity. The 28 sessions and conferences are in addition to the annual meeting, which will take place Monday morning, June 26; the conference of officers, delegates, and members, which will be held Monday and Tuesday afternoons; and the general session on Wednesday morning. Meeting headquarters will be in the Hotel Jefferson, which has good facilities with some air-conditioned meeting rooms.

JOINT LUNCHEON MEETING

Tuesday noon a joint luncheon with the St. Louis Electrical Board of Trade has been arranged. The luncheon meeting will be addressed by Lieutenant Colonel T. B. Holliday, U. S. Army Air Forces, Matériel Command, Wright Field, Dayton, Ohio. Colonel Holliday's close connection with the development of electric systems for aircraft places him in a position to give a talk of unusual interest, which will be supplemented by an exhibit of equipment. He also is chairman of the Institute's committee on air transportation.

TECHNICAL SESSIONS AND CONFERENCES

Four sessions on electric equipment for military aircraft will present a variety of papers on generator control, relays, fuses, connectors, generators and electrical instruments, as well as aircraft lighting. Other sessions closely related to the war effort will deal with electric welding, industrial-power applications, electrochemistry and electrometallurgy, industrial control, and quality control by statistical methods as applied to manufacturing. The expanded program will present subjects such as industrial control, induction heating, marine transportation, electronic applications, and electric house heating, which are relatively new fields of activity. In addition, there will be sessions in the central-station field, which will treat the subjects of power generation, transmission, cables, switchgear, and relays, as related to wartime conditions.

To commemorate the Morse telegraph centennial a symposium of papers has been arranged which will review the state of the art of telegraphy after 100 years from several points of view.

HOTEL RESERVATIONS

The hotel committee has reserved accommodations which expire on June 15, at the Hotel Jefferson, headquarters, as well as at the Statler, Mayfair, Lennox, Mark Twain, DeSoto, Coronado, Park Plaza, and Claridge. Everyone expecting to attend the meeting should have filled out and mailed the hotel reservation card, indicating his first and second choices of hotels, addressed to Russell G. Meyerand, chairman of the hotel committee, 901 Syndicate Trust Building, St. Louis 1, Mo. These cards were sent to most of the membership with the mailed announcement of the meeting. The Jefferson will not accommodate everyone expected to attend the meeting, but good rapid transit facilities are available in St. Louis.

ADVANCE REGISTRATION

Members who will attend the meeting should have filled out and mailed in the advance registration card received with the mailed announcement. This will assist the committee in making arrangements and will help to avoid congestion on arrival at the registration desk.

COMMITTEES

Those making the arrangements of the meeting are B. D. Hull, *chairman;* I. T. Monseth, *vice-chairman;* L. L. Crump, *secretary-treasurer;* F. A. Cooper, Jr. (chairman, St. Louis Section). Subcommittee chairmen: C. B. Fall, *finance;* C. H. Kraft, *meetings and papers;* B. T. McCormick, *registration and information;* R. G. Meyerand, *hotels;* E. S. Rehagen, *hospitality;* Guy W. Thaxton, *transportation and trips;* L. F. Woolston, *publicity.*

Future AIEE Meetings

Summer Technical Meeting
St. Louis, Mo., June 26–30, 1944

Pacific Coast Technical Meeting
Los Angeles, Calif., Aug. 29–Sept. 1, 1944

Memorial Plaza, St. Louis, Mo., only a few blocks from the Jefferson Hotel, headquarters for the 1944 AIEE summer technical meeting. Clustered around a central park area are some of the newest and most highly prized edifices in the city. Near by are the city's new police headquarters and the Central Public Library

AIEE Summer Technical Meeting

● **ABSTRACTS** of most papers appear on pages 25–352 of this issue and pages 146–7 of the April 1944 issue.

● **PRICES** and instructions for procuring advance copies of these papers accompany the abstracts. Only numbered papers are available in pamphlet form.

Monday, June 26

9:30 a.m. **Registration**

10:00 a.m. **Annual Meeting**

President Nevin E. Funk, presiding

Address of welcome, **William McClellan**, AIEE Past President

Board of directors' report (in abstract), **H. H. Henline**, national secretary

National treasurer's report, **W. I. Slichter**

Committee of tellers' report on election of officers

Introduction of president-elect and presentation of president's badge; response by **President-Elect, Charles A. Powel**

Report on Institute prizes for papers, **F. A. Cowan**, chairman, committee on award of Institute prizes; presentation by **President Nevin E. Funk**

Presentation of Lamme Medal to **Arthur H. Kehoe**

Presentation of Faraday Medal of Institution of Electrical Engineers to Irving Langmuir

Any other business that may be presented

President's address, Nevin E. Funk

2:00 p.m. **Conference of Officers, Delegates, and Members**

Tuesday, June 27

9:30 a.m. **Power Generation**

44-98. The Summation of Load Curves. **R. F. Hamilton**, War Production Board

44-85. Prevention of Rotor-Winding Deformation on Turbogenerators. **J. G. Nesst**, Consolidated Edison Company of New York, Inc.

44-106. The Effect of Weather on the System Load. **H. A. Dryar**, Philadelphia Electric Company

44-107. Conditions Controlling the Economic Selection of Prime Movers. **B. G. A. Skrotzki**, Consolidated Edison Company of New York, Inc.

CP.* Progress Report on Turbogenerator Standardization. AIEE group of AIEE–ASME Joint Committee on Turbogenerators

9:30 a.m. **Aircraft Equipment**

44-89. The Differential Generator-Control Relay for D-C Aircraft Electric Systems. **F. E. Crever**, General Electric Company

44-90. Aircraft Fuses Must Protect. **J. C. Lobenz, Jr.**, Bussmann Manufacturing Company

44-108. An Aircraft Differential-Voltage Cutout. **O. C. Walley**, Westinghouse Electric and Manufacturing Company

44-88. A-C Contactors for Aircraft. **F. J. Russell and A. F. Charbonneau**, Cutler-Hammer, Inc.

9:30 a.m. **Basic Sciences**

44-95. Formulas for the Four-Terminal-Network Parameters of Uniform Networks. **W. R. LePage**, The Johns Hopkins University

44-109. Formulas for Calculating Short-Circuit Forces Between Channels Located Back to Back. **T. J. Higgins**, Illinois Institute of Technology

44-110. The Computation of Magnetic-Field Strength of Round Coils of Small Cross Section. **H. B. Dwight and G. O. Peters**, Massachusetts Institute of Technology

44-129. Fundamentals of Hearing-Aid Design. **W. D. Penn**, Vacolite Company

9:30 a.m. **Quality Control by Statistical Methods**

CP.* Developments in the Control of Quality by Statistical Methods. **R. E. Wareham**, General Electric Company

CP.* Educational Courses on Quality Control. **Paul R. Rider**, Washington University

CP.* Application of Statistical Principles to Acceptance Inspection of Ordnance Materiel. **Captain A. R. Burgess**

44-113—ACO.† The Application of Statistics to Dielectrics. **C. M. Summers and K. E. Ross**, General Electric Company

CP.* Statistical Methods for Quality Control. **Joseph Manuel**, Westinghouse Electric and Manufacturing Company

12 m. **Joint Luncheon With St. Louis Electrical Board of Trade**

Address "Aviation and the Electrical Engineer," **Lieutenant Colonel T. B. Holliday**, United States Army Air Forces

2:00 p.m. **Conference of Officers, Delegates, and Members**

2:00 p.m. **Power Transmission**

44-114. The Measurement of Lightning Currents in Direct Strokes. **G. D. McCann**, Westinghouse Electric and Manufacturing Company

44-115. Transmission-Line Electric Loadings. **S. B. Crary**, General Electric Company

44-116. Ring Buses for Generating and Transmission Stations. **E. L. Michelson and J. P. Gallassini**, Commonwealth Edison Company

44-117. Capacitor Installation at Newport News. **V. R. Parrack**, Virginia Public Service Company, and **E. L. Harder**, Westinghouse Electric and Manufacturing Company

44-118. Capacitors, Condensers, and System Stability. **J. W. Butler, T. W. Schroeder, and W. Ridgway**, General Electric Company

44-119. A Method of Approach to the Consideration of Power-Distribution-System Costs. **O. B. Falls, Jr.**, General Electric Company

2:00 p.m. **Aircraft Ignition and Auxiliaries**

44-112. Aircraft Storage-Battery Design. **J. L. Rupp**, National Battery Company.

44-121. Battery Booster Coils for Airplane-Engine Ignition Systems. **A. V. Alvino**, Bendix Aviation Corporation

44-123. Dimensional Study of Lightweight Motors for Aircraft. **W. J. Morrill**, Electric Motors and Specialities Company

44-124. Auxiliary Power-Plant Requirements. **L. E. O'Neil**, Andover Motors Corporation

2:00 p.m. **Electric Welding**

44-101. Rating of Electric Equipment Under Intermittent Load. **Myron Zucker**, Mackworth G. Rees, Inc.

44-125. An Improved Electronic Control for Capacitor-Discharge Resistance Welding. **H. J. Bichsel and E. T. Hughes**, Westinghouse Electric and Manufacturing Company

44-105. The Design of Low-Voltage Welding-Power Distribution. **C. A. Adams, J. R. Fetcher, and A. C. Johnson, E. G. Budd** Manufacturing Company

CP.* The Use of Constant-Current Regulators and Capacitors to Provide Satisfactory Distribution-System Design Where Serving Welding Loads. **E. R. Hendrickson and R. O. Askey**, Public Service Company of Northern Illinois

Wednesday, June 28

10:00 a.m. **General Session**

2:00 p.m. **Morse Telegraph Centennial**

44-126. Developments in the Field of Cable and Radiotelegraph Communications. **Haraden Pratt**, Mackay Radio and Telegraph Company, and **J. K. Roosevelt**, All America Cables and Radio, Inc.

44-127. American Telegraphy After 100 Years. **F. E. d'Humy and P. J. Howe**, Western Union Telegraph Company

44-128. Telegraphy in the Bell System. **R. D. Parker**, Bell Telephone Laboratories, Inc., and **J. A. Duncan and R. E. Pierce**, American Telephone and Telegraph Company

2:00 p.m. **Power Cables**

44-130. Impulse Strength of Insulated-Power-Cable Circuits. **Herman Halperin**, Commonwealth Edison Company and **G. B. Shanklin**, General Electric Company

44-131. Cyclic Movement of Cable—Its Causes and Effects on Cable Sheath Life. **C. S. Schifreen**, Philadelphia Electric Company

44-132. An Investigation of the Relationship Between Temperature and Movement of Cables in Ducts. **C. T. Nicholson and T. J. Brosnan**, Buffalo Niagara Electric Corporation

44-133. Gas-Filled Cable Research and Experience. **G. B. Shanklin**, General Electric Company

44-134. Operation of Low-Pressure Gas-Filled Cable. **C. T. Hatcher**, Consolidated Edison Company of New York, Inc.

2:00 p.m. **Aircraft Lighting and Instruments**

44-136. Gaseous-Discharge Lamps for Airplane Lighting Service. **E. W. Beggs**, Westinghouse Electric and Manufacturing Company

44-91. Lighting Required for Commercial Airline Aircraft. **W. A. Petrasek**, American Airlines, Inc.

44-138. Aircraft-Engine Torque Meters. **F. W. Godsey, Jr.** and **B. F. Langer**, Westinghouse Electric and Manufacturing Company

44-149. Magnesyn Remote Indication. **R. S. Childs**, Bendix Aviation Corporation

2:00 p.m. **Industrial Control**

44-139. The Degree of Short-Circuit Protection Afforded Small Low-Voltage A-C and D-C Starters by Means of Fuses and Circuit Breakers. **B. W. Jones**, General Electric Company

44-140. Insulation Temperature Standards for Industrial-Control Coils. **B. W. Erikson**, General Electric Company

44-141. Industrial Control: Shunted-Armature Connection for a D-C Shunt Motor. **G. F. Leland and L. T. Rader**, General Electric Company

44-142. Modern Cargo-Winch Control for Use on Victory Ships. **F. H. Holt**, General Electric Company

CP.* Grid Control for Gaseous-Discharge Tubes. **P. T. Chin and E. E. Moyer**, General Electric Company

2:00 p.m. **Conference on Problems in Engineering Colleges and Their Effects in Industry**

CP.* Postwar Courses and Curricula in Electrical Engineering. **R. G. Kloeffler**, Kansas State College

CP.* Interpretation of Present Hiatus in Electrical-Engineering Education on Industrial Postwar Demands for Engineers. **J. L. Hamilton**, Century Electric Company

3:30 p.m. **Clinic on College and High-School Student Counseling**

CP.* Co-operation of Sections. **G. W. Bower**, chairman, Sections committee

St. Louis, Mo., June 26–30, 1944

CP.* Values of Counseling to High-School Students. T. L. Jones, chairman, educational committee, St. Louis Section

CP.* High-School-Student Counseling in Metropolitan New York Area. S. P. Shackelton, chairman, student guidance committee, New York Section

CP.* Ways and Means of Sections Co-operating With College AIEE Branches. R. C. Gerham, University of Pittsburgh

Thursday, June 29

9:30 a.m. Symposium on Electronic Frequency Converters

44-143. History and Development of the Electronic Power Converters. E. F. W. Alexanderson and E. L. Phillipi, General Electric Company

44-144. The Electronic Converter for Exchange of Power. F. W. Cramer, Carnegie-Illinois Steel Corporation, and L. W. Morton and A. G. Darling, General Electric Company

44-145. Design of an Electronic Frequency Changer. C. H. Willis, Princeton University, and R. W. Kuenning, E. F. Christensen, and B. D. Bedford, General Electric Company

44-146. Switchgear and Control for an Electronic Power Converter. W. N. Gittings and A. W. Bateman, General Electric Company

44-147. Pentode Ignitrons for Electronic Power Converters. H. C. Steiner, J. L. Zehner, and H. E. Zuvers, General Electric Company

9:30 a.m. Aircraft Instruments

44-152. A Unique Moving-Magnet Ratio Instrument. F. R. Sias and D. B. Fiak, General Electric Company

44-153. Recent Advances in Aircraft-Tachometer Design. R. G. Ballard and C. P. Hall, General Electric Company

44-150. Design Considerations in Aircraft Instruments to Meet War Service. C. F. Savage and J. M. Whittenton, General Electric Company

44-151. Electrically Operated Gyroscopic Instruments. H. Konet, Bendix Aviation Corporation

44-148. Totalizing Contents of Aircraft Fuel Tanks. J. R. Macintyre, General Electric Company

9:30 a.m. Heating Houses Electrically

44-154. Load-Calculation Procedure for Electric-Panel Space Heating. B. F. Raber and F. W. Hutchinson, University of California

44-155. Electrothermal Space Heating and Air Conditioning. G. H. Krueger, Bonneville Power Administration

44-156. Possibilities of Heat Pumps for Heating Homes. R. U. Berry, General Electric Company

9:30 a.m. Conference on Temperature Standards

The purpose of the conference sessions is to review temperature standards including hot-spot allowances for rotating machines in the fractional- and integral-horsepower sizes. These sessions represent a continuation of the activity started at the winter technical meeting in New York, N. Y., January 24–28, 1944. There will be a series of conference papers presented giving actual test results of temperature tests on various types and sizes of motors.

Those expected to present conference papers are as follows:

L. E. Hildebrand, General Electric Company

L. H. Hirsch, Century Electric Company

W. R. Hough, Reliance Electric and Engineering Company

H. M. Joy, Master Electric Company

T. C. Lloyd, Robbins and Meyers, Inc.

R. F. Munier, Emerson Electric Manufacturing Company

F. D. Phillips, General Electric Company

M. L. Schmidt, General Electric Company

P. H. Trickey, Diehl Manufacturing Company

C. P. Potter, Wagner Electric Corporation

2:00 p.m. Conference on Temperature Standards (continued)

2:00 p.m. Switchgear

44-157. Protection of Large D-C Machines by Means of High-Speed Circuit Breakers. J. Elmer Housley, Aluminum Company of America and Otto Jensen, I-T-E Circuit Breaker Company

44-102. A Pneumatic Mechanism for Outdoor Oil Circuit Breakers. L. J. Linde and E. B. Rietz, General Electric Company

44-158. Improved Selective Tripping of Low-Voltage Air Circuit Breakers. C. P. West, Westinghouse Electric and Manufacturing Company

44-97. Fusing Practices on Distribution Systems—II. J. S. Parsons and J. M. Wallace, Westinghouse Electric and Manufacturing Company

44-159. Fault Protection on Shipboard A-C Power-Distribution Systems. Captain H. G. Rickover and P. N. Ross, Bureau of Ships, Navy Department

2:00 p.m. Electronics and Measurements

44-78. Development of Excitron-Type Rectifier. H. Winograd, Allis-Chalmers Manufacturing Company

44-11. Analysis of Rectifier Circuits. E. F. Christensen and C. C. Herskind, General Electric Company, and C. H. Willis, Princeton University

44-160. Operation of Rectifiers Under Unbalanced Conditions. E. F. Christensen and M. M. Morack, General Electric Company

44-161. A Resonant-Cavity Method for Measuring Dielectric Properties at Ultrahigh Frequencies. C. N. Works, T. W. Dakin, and F. C. Boggs, Westinghouse Electric and Manufacturing Company

C.P.* High-Frequency Cable Design and Testing. N. D. Kennedy, P. W. Ware, Simplex Wire and Cable Company

2:00 p.m. Conference on Experiences With Electric House Heating

CP.* Electric Heating of Small Homes in the Tennessee Valley. B. H. Martin, Tennessee Valley Authority

CP.* Reverse Refrigeration Applied to a New Haven Office Building. E. H. Walton and C. A. Williams, United Illuminating Company

4:00 p.m. Open Meeting of Committee on Domestic and Commercial Applications

CP.* Report of Subcommittee on Farm Application. C. H. Leatham, Monongahela West Penn Public Service Company

CP.* Report of Subcommittee on Hazards to Farm Animals. W. B. Buchanan, Hydro-Electric Power Commision of Ontario

CP.* Report of Subcommittee on Wiring Matters. Wesley Weinerth, Philadelphia Electric Company

Friday, June 30

9:30 a.m. Electrochemistry and Electrometallurgy

44-163. The Copper-Oxide Rectifier in Electrochemical Work. I. R. Smith, Westinghouse Electric and Manufacturing Company

44-164. Electronic Regulator for Arc Furnaces. J. E. Reilly and C. E. Valentine, Westinghouse Electric and Manufacturing Company

44-165. Characteristics of Chlorinated Impregnants in D-C Paper Capacitors. L. J. Berberich, C. V. Fields, and R. E. Marbury, Westinghouse Electric and Manufacturing Company

44-100. Treatment and Casting of Metals by Electromagnetic Forces. W. W. Hoke, Garden City, N. Y.

44-166. Induction Heating—Selection of Frequency. N. R. Stansel, General Electric Company

44-167-ACO.† Application of Industrial Generators to Induction Heating. E. H. Browning, Westinghouse Electric and Manufacturing Company

44-168. Surface Heating by Induction. H. F. Storm, Allis-Chalmers Manufacturing Company

44-99. Voltage Transients in Arc-Furnace Circuits. Subcommittee on transient voltages in arc-furnace circuits

9:30 a.m. Transformers

44-169. Progress in Impulse Testing of Transformers. J. H. Hagenguth, General Electric Company

44-170. High-Voltage Compressed-Gas Power Transformers. H. M. Hobart, consulting engineer

44-171. The Design and Operating Characteristics of Modern Dry-Type Air-Cooled Transformers. W. W. Satterlee, Westinghouse Electric and Manufacturing Company

44-103. Hot-Spot Temperatures in Dry-Type Transformer Windings. H. C. Stewart and L. C. Whitman, General Electric Company

CP.* Standard Current Transformers With One-Ampere Secondary Winding. L. F. Hunt and J. H. Vivian, Southern California Edison Company, Ltd.

9:30 a.m. Industrial Power Applications

44-178. Extending the Use of Shunt Capacitors by Means of Automatic Switching. W. H. Cuttino, Westinghouse Electric and Manufacturing Company

44-173. Automatic Control and Switching Equipment for Capacitor Banks and Its Application. T. W. Schroeder and W. C. Bloomquist, General Electric Company

CP.* Electric-Power Distribution for Industrial Plants. Report of AIEE committee on industrial power applications

CP.* Dodge Chicago Plant's Electric-Power-Distribution Scheme With Airplane-Engine Testing Power-Recovery Circuits. E. L. Bailey, Chrysler Corporation

2:00 p.m. Relays

44-104. Bibliography of Relay Literature 1940–43. Working group on relay bibliography, AIEE relay subcommittee

44-172. A New Frequency Relay for Power-System Applications. H. J. Carlin and J. L. Blackburn, Westinghouse Electric and Manufacturing Company

44-94. The Evolution of Standard Lines of Current Transformers for High Overcurrent Capacity. L. C. Wents, Westinghouse Electric and Manufacturing Company

44-93. Current-Transformer Output and Application Charts. R. Koller, Pacific Electric Manufacturing Corporation

44-135. A New Carrier Relaying System. T. R. Halman and A. F. Dromgp, Detroit Edison Company and S. L. Goldsborough and H. W. Lenanse, Westinghouse Electric and Manufacturing Company

2:00 p.m. Land Transportation

44-92. Modern Motive Power for the Sorocabana Railway. R. L. Chapman and O. K. Kjolseth, General Electric Company

44-96. Economics of Trolley-Coach Operation. G. M. Woods, Westinghouse Electric and Manufacturing Company

2:00 p.m. Motors and Related Subjects

44-174. Interlamination Resistance. J. P. Barton, Carnegie-Illinois Steel Corporation

44-175. Transient Performance of Induction Motors. F. J. Maginniss and N. R. Schultz, General Electric Company

44-176. Differential Leakage With Respect to the Fundamental Wave and to the Harmonics. M. M. Liwschitz, Westinghouse Electric and Manufacturing Company

44-177. The Nature of Vibration in Electric Machinery. T. D. Graybeal, University of California

*CP: Conference presentation; no advance copies of papers available; not intended for publication in *Transactions*.

†ACO: Advance copies only available; not intended for publication in *Transactions*.

Section and Branch Activities—Annual Report for 1943-44

The following constitutes the annual report on Institute Section and Branch activities for the fiscal year which ended April 30, 1944. Similar information for three preceding fiscal years appeared in *Electrical Engineering* in June 1943, pages 264–5; June 1942, pages 322–3; June 1941, pages 285–7.

Present members of the Sections committee and the committee on Student Branches, which supervise the divisions of Institute activities covered by this report, are:

Sections—G. W. Bower, chairman; R. M. Pfalzgraff, vice-chairman; A. C. Muir, secretary; O. C. Brill, M. S. Coover, C. A. Faust, Frederick Krug, S. J. Lisberger, E. T. Mabood, W. B. Morton, C. S. Purnell, E. W. Schilling, J. M. Thomson, and, ex officio, the chairmen of all Sections of the Institute.

Branches—R. G. Warner, chairman; E. W. O'Brien, vice-chairman; H. H. Henline, secretary; L. A. Bingham; H. L. Davis, Jr.; A. G. Ennis; Everett S. Lee; H. C. Madsen; E. M. Strong; and, ex officio, all Students Branch counselors.

Table I. Section Membership and Meetings During Year Ending April 30, 1944

Section	AIEE Members August 1942	AIEE Members August 1943	Number of Meetings	Average Attendance
Akron	94	87	8	67
Alabama	44	42	3	
Arizona	37	37	9	43
Boston	516	575	8	227
Special technical meeting			1	32
Central Indiana	133	132	10	202
Chicago	836	849	7	150
Power group			4	77
Industrial group			3	73
Communication group			2	92
Cincinnati	214	151	9	90
Cleveland	376	368	9	112
Special technical meetings			3	55
Columbus	95	82	5	78
Zanesville Subsection			12	21
Connecticut	333	361	8	118
Dayton		122	7	93
Aircraft electrical group			3	101
Denver	180	186	9	88
East Tennessee	145	134	10	49
Erie	65	71	7	27
Florida	111	136	4	24
Fort Wayne	93	100	8	53
Georgia	119	101	10	80
Houston	133	153	8	80
Beaumont Subsection			4	80
Iowa	84	80	12	39
Ithaca	53	60	8	97
Kansas City	140	143	10	88
Lehigh Valley	188	189	8	69
Los Angeles	540	548	10	183
Aircraft division			6	180
Electronics division			6	262
Louisville	73	75	11	30
Lynn	186	202	7	174
Popular lectures			4	1,350
Madison	73	75	5	9
Rock River Valley Subsection			5	80
Mansfield	71	68	7	63
Maryland	322	349	8	172
Memphis	56	57	10	35
Mexico	53	57	11	105
Michigan	418	398	6	315
Round-table meetings			5	69
Industrial power committee			2	135
Milwaukee	313	338	8	189
Power applications and control			4	33
Electronics			5	64
Electrical machinery			4	25
Minnesota	98	118	12	44
Power group meeting			1	45
Montana	45	40	9	97
Montreal		148	12	91
Ottawa Subsection			2	40
Muscle Shoals	33	23	4	
Nebraska	59	50	5	36
New Mexico–West Texas	43	48	8	18
New Orleans	133	141	9	57
New York	3,447	3,586	4	210
Communication group			4	233
Power and industrial group			5	384
Transportation group			3	391
Basic science group			4	208
Illumination group			4	201
Niagara Frontier	198	186	9	84
Niagara Falls Subsection			4	55
North Carolina	107	99	2	77
North Texas	170	164	7	58
Oklahoma City	104	90	8	75
Philadelphia	809	863	8	107
Aircraft electrical engineering discussion group			3	24
Instruments and measurements group			3	83
Communication discussion group			4	150
Industrial-practice discussion group			3	32
Power discussion group			2	49
Foremen's discussion group			6	17
Pittsburgh	662	657	9	154
Pittsfield	194	195	7	103
Popular lectures			6	1,175
Portland	196	177	10	77
Transmission and distribution committee			2	66
Communication committee			2	36
Providence	100	93	8	85
Rochester	112	121	9	116
Luncheon meetings			4	43
St. Louis	360	295	10	106
San Diego	54	56	8	62
San Francisco	549	601	17	109
Schenectady	559	630	9	159
Seattle	230	249	10	146
Sharon	153	162	9	74
South Bend	58	48	10	54
South Carolina	53	55	2	60
South Texas	53	50	8	30
Spokane	82	85	7	42
Springfield	52	51	6	85
Syracuse	119	129	5	84
Toledo	89	88	8	138
Toronto	396	379	11	200
Hamilton Subsection			7	
Tulsa	87	79	9	47
Urbana	78	77	4	33
Illinois Valley Subsection			10	58
Utah	64	85	7	52
Vancouver	95	98	11	78
Virginia	150	147	3	110
Washington	600	675	8	220
West Virginia	39	38	6	65
Wichita	57	62	11	48
Worcester	63	57	7	80
Totals	16,644	17,321	738	
Total Sections 73	Total attendance, 83,120			

Table II. Branch Meetings Held During Year Ending April 30, 1944

Branch	Number	Average Attendance
Akron, University of		
Alabama Polytechnic Institute	14	
Alabama, University of	9	11
Alberta, University of	9	32
Arizona, University of	4	10
Arkansas, University of	2	12
British Columbia, University of	13	27
Brooklyn, Polytechnic Institute of		
Day division	12	28
Evening division		
Brown University	11	12
Bucknell University	5	33
California Institute of Technology	1	14
California, University of	9	31
Carnegie Institute of Technology	27	34
Case School of Applied Science	5	24
Catholic University of America	4	6
Cincinnati, University of	3	21
Clarkson College of Technology	7	22
Clemson Agricultural College	3	13
Colorado State College	7	12
Colorado, University of	11	42
Columbia University	1	27
Connecticut, University of	5	55
Cooper Union		
Day division	7	24
Evening division	1	12
Cornell University	11	76
Delaware, University of		
Denver, University of	3	14
Detroit, University of		
Drexel Institute of Technology	7	11
Duke University	8	28
Florida, University of		
George Washington University	7	27
Georgia School of Technology	1	10
Harvard University		
Idaho, University of	12	14
Illinois Institute of Technology		
Illinois, University of	10	27
Iowa State College	9	65
Iowa, University of	19	18
Johns Hopkins University	2	30
Kansas State College	13	42
Kansas, University of	4	16
Kentucky, University of	4	18
Lafayette College	3	33
Lehigh University	9	47
Louisiana State University	12	15
Louisville, University of	4	26
Maine, University of		
Manhattan College	1	17
Marquette University	9	21
Maryland, University of	9	14
Massachusetts Institute of Technology	4	75
Michigan College of Mining and Technology	6	24
Michigan State College	4	18
Michigan, University of	10	41
Milwaukee School of Engineering	3	15
Minnesota, University of	1	125
Mississippi State College	3	14
Missouri School of Mines and Metallurgy	6	39
Missouri, University of	4	51
Montana State College	20	11
Nebraska, University of	17	32
Nevada, University of	6	7
Newark College of Engineering	6	20
New Hampshire, University of	7	24
New Mexico State College		
New Mexico, University of	11	30

Table II. (Continued)

Branch	Number	Average Attendance
New York, College of the City of		
Day division	12	78
Evening division		
New York University		
Day division	1	20
Evening division	5	14
North Carolina State College	7	16
North Dakota Agricultural College	2	5
North Dakota, University of		
Northeastern University	6	45
Northwestern University	2	30
Norwich University		
Notre Dame, University of	6	19
Ohio Northern University	11	18
Ohio State University	5	26
Ohio University		
Oklahoma Agricultural and Mechanical College		
Oklahoma, University of	6	20
Oregon State College	6	64
Pennsylvania State College	4	32
Pennsylvania, University of	1	23
Pittsburgh, University of	46	83
Puerto Rico, University of		
Pratt Institute	8	45
Princeton University	1	20
Purdue University	8	164
Rensselaer Polytechnic Institute	3	41
Rhode Island State College		
Rice Institute	5	26
Rose Polytechnic Institute	8	16
Rutgers University	4	17
Santa Clara, University of	8	10
South Carolina, University of	9	22
South Dakota State College	1	7
South Dakota State School of Mines	3	21
Southern California, University of	11	20
Southern Methodist University	3	28
Stanford University	4	41
Stevens Institute of Technology		
Swarthmore College	3	17
Syracuse University	1	16
Tennessee University of	19	25
Texas Agricultural and Mechanical College		
Texas Technological College	3	29
Texas, University of	2	20
Tufts College	3	72
Tulane University	8	19
Union College	10	35
Utah, University of	4	30
Vanderbilt University		
Vermont, University of		
Villanova College	7	33
Virginia Military Institute		
Virginia Polytechnic Institute	16	27
Virginia, University of		
Washington, State College of	4	29
Washington, University of	3	53
Washington University	9	18
West Virginia University	19	14
Wisconsin, University of	9	33
Worcester Polytechnic Institute		
Wyoming, University of	1	9
Yale University	3	143

Total—125 Branches

Table III. Section Meetings Held During Last Three Fiscal Years

	Fiscal Year Ending April 30		
	1942	1943	1944
Number of Sections	72	73	73
Number of meetings held	647	598	738
Average number of meetings	9.0	8.2	10.1
Total attendance	78,254	66,111	83,120
Average attendance per meeting	121	112	112.6

Table IV. Branch Meetings Held During Last Three Fiscal Years

	For Year Ending April 30		
	1942	1943	1944
Number of Branches	124	125	125
Number of meetings held	946	942	755
Average number of meetings	7.6	7.5	6.0
Total attendance	37,785	38,227	24,768
Average attendance per meeting	39.9	40.6	32.8

Table V. Conferences on Student Activities

District	Location	Date
5	Chicago, Ill.	6/19/43
8 and 9 and University of British Columbia	Salt Lake City, Utah (Pacific Coast technical meeting)	9/3/43
4	Roanoke, Va. (Southern District technical meeting)	11/17/43
2	Pittsburgh, Pa.	1/11/44
1	Boston, Mass. (North Eastern District technical meeting)	4/19/44

Table VI Section or Joint Section and Branch Meetings With Active Student Participation

Sections	Branches	Date	Student Talks	Attendance
Urbana	University of Illinois	5/28/43	2	13
North Carolina	North Carolina State College	11/8/43	1	81
Akron	University of Akron	1/11/44	4	49
North Texas	Southern Methodist University	1/24/44	3	52
New Orleans	Tulane University	2/9/44	1	54
Vancouver	University of British Columbia	3/6/44	4	71
Chicago	Illinois Institute of Technology and Northwestern Technological Institute	4/11/44	4	28
Lehigh Valley	Bucknell University and Lehigh University	4/14/44	1	163
Iowa	University of Iowa	4/21/44	5	
Totals—9 Sections, 11 Branches, 9 meetings			25	511

Subsection Formed in Ottawa

The newest addition to the Institute's lengthening list of Subsections was formed in Ottawa, Ont., February 9, 1944, within the territory of the Montreal Section.

The 11 members and 21 nonmembers present elected the following officers:

Chairman, B. G. Ballard (A '33) associate research engineer, National Research Council.

Vice-chairman, W. G. C. Gliddon (A '28) chief engineer, Gatineau Power Company.

Secretary, J. H. Simpson (A '39) junior research engineer, National Research Council.

Discussion of the relationship of the AIEE with the Engineering Institute of Canada defined the former as filling the technical needs of electrical engineers and left such general questions as the professional status of the engineer within the province of the Engineering Institute of Canada.

At an executive meeting of the Subsection held February 16, the following committee was appointed to draft the necessary bylaws: W. G. C. Gliddon; E. G. Cullwick (M '33) lieutenant commander in the Royal Canadian Naval Volunteer Reserve; and D. S. Smith (A '33) junior research engineer, National Research Council.

1944 Lamme Medal Nominations Due December 1

Special attention is directed to the fact that the names of Institute members who are considered eligible for the AIEE Lamme Medal, to be awarded early in 1945, may be submitted by any member in accordance with section 1 of article VI of the bylaws of the Lamme Medal committee, as follows:

The committee shall cause to be published in one or more issues of *Electrical Engineering*, or of its successors, each year, preferably including the June issue, a statement regarding the "Lamme Medal" and an invitation for any member to present to the national secretary of the Institute by December 1, the name of a member as a nominee for the medal, accompanied by a statement of his "meritorious achievement" and the names of at least three engineers of standing, who are familiar with the achievement.

Each nomination should give concisely the specific grounds upon which the award is proposed, and also a complete detailed statement of the achievements of the nominee to enable the committee to determine its significance as compared with the achievements of other nominees. If the work of the nominee has been of a somewhat general character in co-operation with others, specific information should be given regarding his individual contributions. Names of endorsers should be given as specified in the foregoing quotation.

ABSTRACTS • • •

TECHNICAL PAPERS previewed in this section will be presented at the AIEE summer technical meeting, St. Louis, Mo., June 26-30, 1944, and are expected to be ready for distribution in advance pamphlet form within the current month. Copies may be obtained by mail from the AIEE order department, 33 West 39th Street, New York 18, N. Y., at prices indicated with the abstract; or at five cents less per copy if purchased at AIEE headquarters or at the meeting registration desk.

Mail orders will be filled AS PAMPHLETS BECOME AVAILABLE

Air Transportation

44-89—The Differential Generator-Control Relay for D-C Aircraft Electric Systems; *F. E. Crever (A '27). 20 cents.* The characteristics of both the definite pick-up type of generator control relay and the new differential type are analyzed and compared

from the standpoint of chatter. Also, it is explained how equalizing coils on the regulators of the generators enable positive action in coming on a live bus with differential-type relays. The results of flight tests on a four-engined airplane are shown by oscillograms recorded in flight which substantiate the contention that the differential type is superior. An analysis of a system of N generators in parallel is made for the purpose of determining the percentage load necessary to cause any relay to close on its generator. It is shown that for a given differential setting and equalizer strength this is a fixed percentage load of the connected generators regardless of the number of generators on or off the bus.

44-88—A-C Contactors for Aircraft; *F. J. Russell* (*M '37*), *A. P. Charbonneau* (*Application pending*). *15 cents.* Use of a-c power systems on aircraft presents the problem of providing suitable switching apparatus. Contactors with the desired characteristics and of suitable size and weight have not been available. An analysis is made of contactor ratings and performance characteristics to fill the needs of proposed aircraft. Many of the problems encountered in designing contactors to meet these requirements are discussed. Contactors with continuous current ratings from 5 to 100 amperes and a circuit breaker, rated at 120 amperes with a short circuit capacity of 4,000 amperes for use on 208-volt three-phase 400-cycle systems, are illustrated and described.

44-90—Aircraft Fuses Must Protect; *J. C. Lebens, Jr.* (*A '41*), *15 cents.* The evolution of the electrical system in aircraft has paralleled the development of the plane itself. Today, when the very heart of the airplane is its electrical system, faulty operation of protective devices cannot be countenanced. Complete protection can be obtained only by a device having the same time–current characteristic as that of the equipment it is protecting. This paper covers the fundamentals involved in the protection problem and describes a method whereby it can be solved by adapting a device, already proved in power applications, to meet the requirements imposed by aircraft.

44-108—An Aircraft Differential-Voltage Cutout; *O. C. Walley* (*A '44*). *15 cents.* Experience obtained with present multiengine aircraft electric systems indicates a need for preventing interchange of current between generators when the system is operating at light loads. Such current interchange causes reverse-current cutouts of conventional design to connect and disconnect their respective generators to the system so rapidly that the action is called "chatter." Conventional cutouts connect the generator to the system when the generator voltage is above a preset value. The differential-voltage reverse-current cutout connects the generator to the system when the generator voltage is a preset value above the system voltage. A description is given on the design, operation, and advantages of a differential-voltage reverse-current cutout which prevents interchange of current between the generators.

44-91—Lighting Required for Commercial Airline Aircraft; *W. A. Petrasek* (*A '36*). *15 cents.* A review of the lighting requirements of commercial-airline aircraft discloses the need for additional development of aircraft-lighting equipment. All phases of the aircraft-lighting problem are discussed and the applicable Civil Aeronautics Authority regulations presented. Actual airline operating experience forms the basis for the stated requiremcnts. The subject logically is divided into two general classifications, namely, internal and external lighting. Under the heading of external lighting are the position lights, landing lights, wing-ice lights, and wheel lights. Among the internal lights discussed are the cabin, compartment, and cockpit lights. The relative advantages and disadvantages of the various types of instrument-panel lighting are given, and the importance of suitable cockpit lighting is stressed. The greatest postwar improvement is expected to be the application of fluorescent lighting to the aircraft cabin.

44-124—Auxiliary-Power-Plant Requirements; *L. E. O'Neil. 15 cents.* Designers of electrical equipment for aircraft are confronted with many limitations. Some of these limitations may be nullified by the use of auxiliary power plants. To cover various phases of application a series of engine generators would be necessary. A large number of their design features should be adapted to each type of airplane in order to save weight and obtain best performance. This necessitates close co-operation between designers of the component parts of the airplane.

44-136—Gaseous-Discharge Lamps for Airplane-Lighting Service; *E. W. Beggs. 15 cents.* Fluorescent lamps function well on 400-cycle alternating current which is widely used in airplanes. The efficiency is increased about 20 per cent and, of course, flicker is practically eliminated. Tests showed slightly less drop in lumen output with low-temperature ambient air when operated on 400-cycle instead of on 60-cycle current. Dependable low-temperature starting also is readily obtainable at the higher frequency by means of a small condenser in series with the starting switch of a thermal starter. The 400-cycle operation results in low lamp volts and high amperes for normal lamp wattage. The low lamp voltage provides steady operation but the high-ampere value tends to overload the electrodes somewhat so that to achieve long life the lamps should be run somewhat below normal wattage. The starting voltage of neon-glow lamps on 400-cycle systems is appreciably higher than on 60 cycles. These lamps are practically unaffected by low ambient temperatures on either frequency.

44-148—Totalizing Contents of Aircraft Fuel Tanks; *J. R. Macintyre* (*A '41*). *15 cents.* In an airplane using more than one instrument to indicate the fuel quantity in its tanks, the pilot must add the readings of all instruments to learn his total fuel supply. A single-dial totalized indication of the fuel supply is desirable, because it saves the all-important factor of time, in addition to eliminating the possibility of arithmetical error. The problem of totalizing two or more liquid levels in aircraft fuel tanks falls into two broad classifications. The first of these involves the addition of levels in a single tank where the sequence of use is definitely established. The second covers the totalization of several liquid levels in different tanks, where the sequence of use may vary widely with conditions. This paper describes methods for accomplishing both types of totalizing by means of a remote indicating equipment consisting of transmitter units installed in the fuel tanks and connected electrically to a moving-magnet ratio-type instrument.

44-138—Aircraft-Engine Torque Meters; *F. W. Godsey, Jr.* (*M '36*), *V. F. Langer. 15 cents.* Flight operations experience has shown that significant improvements in fuel economy may be obtained through the use of aircraft-engine torquemeters as regular flight instruments. This paper describes the better-known types of torquemeters and introduces a new type that recently has come through its development stage.

44-150—Design Considerations in Aircraft Instruments to Meet War Service; *C. F. Savage* (*M '43*), *J. M. Whittenton* (*A '37*). *25 cents.* New conditions imposed by the rapid advancement in aviation have challenged industry to develop instruments capable of meeting rigid war requirements. This paper describes generally and specifically how the design features of aircraft instruments have been influenced by wide ranges of operating temperatures, extreme conditions of shock and vibration, extension of altitude ranges, world-wide climatic conditions, adoption of new power supplies for aircraft, standardization of mechanical features necessary because of large-scale use, and the requirements of servicing. The design features discussed are generally applicable to all aircraft instruments.

44-152—A Unique Moving-Magnet Ratio Instrument; *F. R. Sias, D. B. Fisk. 15 cents.* A unique type of moving-magnet d-c ratio instrument is described in this paper. Its performance characteristics compare favorably with those of moving-coil instruments and, in addition, it has the characteristics of simplicity, ruggedness, and compactness. The instrument is readily adaptable to the measurement of temperature by means of bridge circuits utilizing resistance bulb detectors. In this type of circuit the instrument is compensated well for voltage and ambient temperature variations. Inferred uses include the measurement of ohms, current ratios, voltage ratios, telemetering, and voltage-weighted current indications. The structure includes a diametrically magnetized moving element, a dual-purpose damping structure and coil form, two mutually perpendicular sets of coils, and an enclosing magnetic return path and shield. The direction of the vector, resultant of the fluxes caused by currents in the two sets of coils, determines the position of the moving element.

44-153—Recent Advances in Aircraft-Tachometer Design; *R. G. Ballard* (*A '42*), *C. P. Hall. 15 cents.* This paper discusses the requirements of the magnetic-drag-type tachometer system in wartime production, involving increased operating temperature range, durability in service, and a new degree

of instrument compactness. During the past three years the existing designs have been revised and new designs developed to meet these requirements; the outstanding features and operating characteristics of the new designs are outlined in this article. The design factors involved in both the generators and indicators are broken down to give a detailed report of operating torques and voltages, high- and low-temperature influences on ball bearing life, development of new magnectic materials, and action of luminescent-coated pointers with temperature changes. The paper points out the special applications for tachometer equipment and the probable future trends.

44-112—Aircraft-Storage-Battery Design; *J. L. Rupp. 15 cents.* The paper points out werein the aircraft-battery requirements differ from battery requirements encountered heretofore. Then step-by-step each of the important parts that complete the unit are described and information is given about what has been done in design to cause each part to provide a performance to meet aircraft usage. Attention is called to certain departures that have been made from what may be considered sound practice and reasons for the departures are given. Suggestions for correcting these departures are made and experimental work that is being carried on for further improvement is mentioned. In summarizing the data and experience accumulated a suggested design is offered which should overcome the present deficiencies and meet present requirements.

44-121—Battery Booster Coils for Airplane-Engine Ignition Systems; *A. V. Alvino. 15 cents.* Starting of airplane engines always has provided a problem from the ignition engineer's point of view and many innovations have been introduced in an attempt to provide ideal ignition without increasing the weight of the system. A source of external high-voltage current is provided for starting purposes when it becomes impossible to rotate the engine crankshaft fast enough to produce "coming-in speed" of the magneto. This source may be in the form of a booster magneto, high-voltage booster coil, or low-voltage starting vibrator. The high-voltage booster coil of the vibratory type has superseded the motor or manually operated magneto. It is a device for obtaining a high intermittent voltage from a source of steady low voltage by electromagnetic induction. The low-voltage starting-vibrator method consists of a separate induction coil connected to the magneto primary utilizing it as a transformer and supplying it with alternating impulses of about 150 volts.

44-149—Magnesyn Remote Indication; *R. S. Childs. 15 cents.* Electrical remote-indication systems fulfill an important function on modern aircraft. This paper describes in detail the Magnesyn system of remote indication and includes a brief review of other methods. Magnesyns are a-c-operated devices utilizing permanent magnet rotors at both transmitter and receiver. They have been used widely in remote-indicating compasses but are adaptable to many other problems. The development of the system, theory of operation, performance features, and some applications of the system are discussed.

44-151—Electrically Operated Gyroscopic Instruments; *H. Konet. 15 cents.* Because of the increased use of electricity on aircraft, electrically operated gyroscopic instruments have been used for more applications. This paper described several types of gyro motors and their applications. It also cites the advantages of the electrical gyro over the air-driven gyro.

Basic Sciences

44-95—Formulas for the Four-Terminal-Network Parameters of Uniform-Ladder Networks; *W. R. LePage (M'44). 15 cents.* Uniform-ladder networks usually are treated in terms of their propagation function and characteristic impedances. However, when dealing with only the terminal quantities one is interested in the so-called *A-B-C* parameters, or the driving point and transfer impedances or admittances. These are related to the propagation function by hyperbolic functions; but they are actually rational functions of $p(p=d/dt)$ or frequency. These rational functions are simplest for the *A-B-C* parameters and the driving point and transfer parameters are related to them by simple forms. Therefore, the treatment is in terms of the former. It is shown that the *A-B-C* parameters are all polynomials in the variable $Z_T Y_T$, where these are the total series impedance and shunt admittance of the network, respectively. Explicit formulas are developed for the coefficients of these polynomials for mid-series or mid-shunt termination and the relations between the degrees of the polynomials and the number of network sections easily is established from these formulas.

44-109—Formulas for Calculating Short-Circuit Forces Between Channels Located Back to Back; *T. J. Higgins (A'40). 15 cents.* Formulas are derived for calculating the short-circuit mutual electromagnetic forces exerted between the two conductors of a single-phase bus comprised of channels located back to back. It is assumed that the conductors are nonmagnetic, are of such length that end effects are negligible, and carry currents distributed uniformly over the cross sections and that these cross sections are so thin they may be considered to be comprised of line segments. Once the desired formulas are obtained—through differentiation of the known formula for the inductance of the bus—their use is illustrated by calculation of a typical problem.

44-110—The Computation of Magnetic-Field Strength of Round Coils of Small Cross Section; *H. B. Dwight (F'26), G. O. Peters. 15 cents.* Formulas for the magnetic-field strength near a single round turn of fine wire were published by Andrew Gray and Alexander Russell and have been found very useful with coils the dimensions of whose cross sections are small compared with their radii. In this paper, correction formulas are given to improve the precision of that calculation by bringing in the effect of the section dimensions of length and thickness. The correction terms are comparatively simple. They apply where the distance from the center of the round coil to the point where the field strength is to be computed is distinctly larger than the coil radius or else distinctly smaller. For the latter case, a second set of correction terms is given. A numerical example is given and the time saved by using the correction formulas in a favorable case, instead of other calculations which give equal precision, is shown.

Communications

44-126—Developments in the Field of Cable and Radiotelegraph Communications; *Haraden Pratt (F'37), J. K. Roosevelt (M'30). 15 cents.* This paper reviews the growth, from time of organization to the present, of each of the four telegraph communication companies constituting the system of the International Telephone and Telegraph Corporation which provide services between the United States and foreign countries. These are the All America Cables and Radio, Inc., the Commercial Cable Company, the Commercial Pacific Cable Company, and the Mackay Radio and Telegraph Company. Important elements in the technical developments applicable to the operation of both submarine-cable systems and radiotelegraph systems also are reviewed, showing how the methods and instrumentalities of today grew by process of evolution out of the elementary ways of the early days.

44-127—American Telegraphy After 100 Years; *F. E. d'Humy (F'30), P. J. Howe (A'09). 30 cents.* The telegraph, which is the oldest electrical industry, celebrated its centennial May 24 of this year. Technically, its operations have changed greatly during recent years, but the only data which have been published regarding such changes pertain to specific applications or developments. The present paper is intended to present an over-all picture of American telegraphy, as it is conducted today by the one company which is engaged solely in the telegraph business. The paper describes the nature of telegraph service, discusses the traffic problems associated with the business, and describes the facilities which are employed and the functions which they perform. Although the paper is long by reason of the multiplicity of telegraph services and types of apparatus, only brief references are made to features of plant or equipment which have become stabilized through the years and well understood by the industry. Similarly, no attempt is made to discuss details of technical design or operation, nor the various historical steps by which the telegraph reached its present status. In brief, the paper presents merely a general view of the industry, and a bibliography of its literature, from which anyone who seeks more details, can be guided in his further inquiries.

44-128—Telegraphy in the Bell System; *J. A. Duncan, R. D. Parker (M'14), R. E. Pierce (M'30). 30 cents.* As a part of the Morse centennial, this paper reviews some of the activities in telegraphy carried on by the various units of the Bell System in con-

nection with the furnishing of private-line telegraph and teletypewriter exchange service. At the present time approximately 4,000,000 miles of telegraph circuit facilities are used by the telephone companies, of which about 2,600,000 miles are obtained by carrier methods. Over 34,000 stations, most of which are teletypewriters, are served by these facilities. Frequent reference is made to publications covering developments and present activities. Only those items which have not been disclosed previously are covered in any detail.

44-129—Fundamentals of Hearing-Aid Design; *W. D. Penn (A'35). 20 cents.* Approximately four per cent of the population is sufficiently hard of hearing to require the use of a hearing aid. The nature of the hearing loss varies with the individual. From a knowledge of the characteristics of speech and hearing, the requirements a hearing aid must meet with respect to output, gain, and frequency response are determined. It is found that selective amplification is usually required. A novel method of obtaining the required type of selective amplification is described. The effect of room noise in limiting the maximum amplification which can be used is discussed. A method of computing the over-all acoustical gain is given. Performance curves of an instrument using the type of selective frequency control described are shown.

Domestic and Commercial Applications

44-154—Load-Calculation Procedure for Electric-Panel Space Heating; *B. F. Raber, F. W. Hutchinson. 30 cents.* Radiant heating by means of ceiling panels permits establishing comfort in a room with lower air temperature and with greater feeling of freshness of air than is possible with conventional heating systems. The paper presents three steps to be followed in designing panel-heating systems. These are of particular interest to the electrical engineer, because, as the paper explains, such systems seem to afford an effective means of improving the competitive position of electricity as a primary energy source for space heating. Aside from direct electric panels, the lower operating temperature of panels using *any* heating medium makes off-peak electrical thermal storage more practical, because of smaller equipment, than it is with conventional heating systems; over 250,000 kw of such systems are now in service. Of even greater promise is the possibility of utilizing low-temperature panels with a heat pump for all year conditioning, the lower winter surface temperature and higher summer surface temperature leading to an unusually high coefficient of performance.

44-155—Electrothermal Space Heating and Air Conditioning; *G. H. Krueger. 15 cents.* This paper will cover briefly a historical outline of space heating with a detailed description of the electrothermal off-peak method for space heating and air conditioning. The general principles involved in this method of heating are based on thermodynamic laws. Electrically generated heat energy is stored in hot water contained in a vessel under 200-pounds-per-square-inch pressure at the saturated temperature of 388 degrees Fahrenheit. There is sufficient heat energy stored in the water in the pressure vessel to be liberated as steam into the heating system to supply the building's heating requirements during the peak periods. Therefore, nothing but off-peak energy is used to operate this system. The air conditioning operates on a closed cycle admitting only sufficient fresh air to maintain the proper oxygen and carbon dioxide contents in the air. It also operates at a slight positive pressure within the space to be heated thus preventing infiltration.

44-156—Possibilities of Heat Pumps for Heating Homes; *R. U. Berry (A'29). 15 cents.* Heat pumps are refrigerators in which the principal interest is in the heat output from the condenser. A few installations have been made in which the heat output is used for space heating, and there is a steadily growing interest in them. This paper deals briefly with their efficiency, fuel economy, and output characteristics in an average climate. Initial costs and operating costs are compared with those for fuel-burning systems, and estimates are given on the energy and demand requirements for an average residential system in a typical climate with equipment now available.

Electric Machinery

44-94—Evolution of Standard Lines of Current Transformers of High Overcurrent Capacity; *E. C. Wentz (M'42). 25 cents.* System-fault currents today are generally higher than they were years ago. The first current transformers built for high-current capacity were special designs. When more and more of them were required, the need to standardize the special designs became apparent. The theoretical basis of the new line of standard transformers is a thorough study of the electromagnetic forces produced by the high current. Formulas are developed for calculating these forces. Means for approximating the strengths of the windings against these forces are given and the theory is confirmed by tests to destruction on a number of transformers. The practical basis for the standardized transformers is a line of standard Hipersil cores designed to give uniform performance. A line of transformers is made for each core size for each value of fault current (associated with a standard circuit breaker).

44-103—Hot-Spot Temperatures in Dry-Type Transformer Windings; *H. C. Stewart (M'36), L. C. Whitman (A'39). 25 cents.* This paper gives the results of an extended series of thermal tests on a variety of dry-type transformer coils. Data are presented on the effect of different heights of coil stack, different configurations, and, in addition, some essential precautions in making temperature measurements are pointed out. Hot-spot temperatures were investigated in coils cooled by natural-draft and by forced-air circulation at different velocities for both directed flow and random flow. Hot-spot increments (hot-spot temperature minus average temperature) range from 11 degrees centigrade for short natural-draft-cooled coils to 31 degrees centigrade for tall fan-cooled coils built with class *A* insulation (55 degrees centigrade) as contrasted with 10 degrees centigrade hot-spot allowance as given in American Standards Association, "Standards for Transformers, Regulators, and Reactors, *C*57.1, 1942" Hot-spot increments for class *B* insulation (80 degrees centigrade) vary from 16 to 46 degrees centigrade depending upon coil length and method of cooling. No hot-spot allowance has been established for class *B* insulation. The high hot-spot increments found in these tests show the need for review and modification of the standard allowances for dry-type transformers.

44-139—The Degree of Short-Circuit Protection Afforded Small Low-Voltage A-C and D-C Starters by Means of Fuses and Circuit Breakers; *B. W. Jones (M'43). 15 cents.* The AIEE technical paper 42-79 published in *Transactions*, volume 61, July 1942, pages 483–87, gave data regarding the interrupting ability of low-voltage cartridge-type fuses and their ability to protect small motor starters. These data were misinterpreted by some and it is the purpose of this article to point out the intended interpretation and to illustrate the main point with additional data.

44-140—Insulation Temperature Standards for Industrial-Control Coils; *B. W. Erikson. 15 cents.* It is proposed that higher temperature-rise values for industrial control coils be accepted by the industry, these higher values not to be applied indiscriminately to all designs, but to be used only in conjunction with:

1. Designs utilizing better than average class-*A* heat-resistant materials.
2. Coil constructions where the windings are compact and well supported.
3. Definitely only on circuits rated less than 600 volts.

This proposal is made because:

1. It will result in smaller and lighter designs and less electrical inertia and, therefore, faster contactor operation. The lighter weight also will promote longer life of the moving parts and over-all improved reliability.
2. Experience with many thousands of coils designed under the present National Electrical Manufacturers Association temperature limits over many years of service has been satisfactory.
3. Present day coils utilizing new synthetic insulating materials and improved methods of coil construction have superior life expectancy.
4. The small size, rigidity of construction, and relatively low voltage ratings, enable industrial-control coils to withstand temperatures higher than those permissible for many other applications. For instance, rotating machinery is usually conceded to be far more severe on the insulation system as compared with industrial-control service.

44-141—Industrial Control: Shunted-Armature Connection for a D-C Shunt Motor; *G. F. Leland, L. T. Rader (M'43). 15 cents.* This paper describes the shunted-armature connection used with a d-c shunt motor to obtain speed-torque control. Putting resistance in parallel with the armature, in addition to series line resistance, results in a method of obtaining slow-down control with good speed regulation at low initial cost. A simple graphical method is presented for obtaining the required values of shunt and series resistance to give two speci-

fied speed-torque points. An analytical proof of the method also is included.

44-169—Progress in Impulse Testing of Transformers; *J. H. Hagenguth* (*M '44*). *30 cents.* The paper describes briefly the test circuit and test procedure for impulse testing of transformers. The methods of failure detection and the complexity of the impulse test are discussed on the basis of experience gained in making design and commercial impulse tests on several million kilovolt-amperes of transformers. Experience has shown that not all failures can be detected with present methods. The best and most reliable method available at present is the direct comparison by superposition of cathode-ray oscillograms. Normal frequency excitation, simultaneously applied with the impulse, has been found inconclusive as a failure indicator. It not only increases testing time, but also requires protection practices which are apt to obscure failures. A new method of failure detection is described which is capable of detecting failure of one turn in 1,350 turns. This method should prove very useful as an accurate failure indicator.

44-171—The Design and Operating Characteristics of Modern Dry-Type Air-Cooled Transformers; *W. W. Salterlee* (*M '41*). *15 cents.* This paper describes and discusses modern dry-type air-cooled transformers which are constructed with class-*B* insulation and combinations of organic and inorganic materials. These transformers will operate satisfactorily at relatively high winding temperatures because their insulation structure is designed and arranged to use basically inorganic materials where temperatures in excess of 130 degrees centigrade are attained. The results of tests and operating records show that the effects of humidity are unimportant and that overloads in excess of 150 per cent of rated load may be carried for long periods of time without detrimentally affecting the electrical and mechanical properties of these transformers.

44-174—Interlamination Resistance; *J. P. Barton* (*A '30*). *15 cents.* In laminated core structures for transformers and rotating machines, the need for adequate interlamination resistance becomes more necessary as the core structures increase in size. A method for determination of the minimum interlamination resistance required in terms of the core and its operating conditions, for any degree of stray loss, is developed, resulting in a simple equation. A typical application of the equation is illustrated. The desirability of quality control of the interlamination resistance of finished laminations is reviewed by stating the need for measurement of the resistance at maximum operating temperature, pressure, and stray loss voltage in the core structure to assure adequate insulation of the lamination.

44-175—Transient Performance of Induction Motors; *F. J. Maginniss* (*A '43*), *N. R. Schultz* (*A '40*). *25 cents.* This paper presents the results of a differential-analyzer study of the equations of induction-motor performance. The effects of rotor mechanical load and inertia are included in the analysis. Specific solutions are shown for a number of cases including full-voltage starting, plugging, voltage dip, and short circuits, with emphasis placed on the transient motor torque and current obtained. Comparisons are made between the steady-state and transient speed-torque characteristics.

44-176—Differential Leakage With Respect to the Fundamental Wave and to the Harmonics—Integral-Slot and Squirrel-Cage Windings; *M. M. Liwschitz* (*M '39*). *30 cents.* The standard theories of differential leakage do not consider the damping of this leakage by the currents induced in the secondary winding. They fail entirely when applied to the harmonics. A calculation of the parasitic torques and forces produced by the harmonics in induction motors and salient-pole synchronous machines is not possible on the basis of the standard theories of differential leakage. The object of this paper is to derive formulas for the differential leakage of integral-slot as well as fractional-slot windings taking into account the influence of damping, number of slots of stator and rotor, fractional pitch, and skewing. Special attention is paid also to the slot openings which in machines with open slots influence very considerably the slot harmonics. Curves are given which make it possible to calculate the differential leakage in a simple way. The integral-slot and squirrel-cage windings are treated.

44-177—The Nature of Vibration in Electric Machinery; *T. D. Graybeal* (*A '38*). *20 cents.* Vibration in electric machinery is the result of a number of contributing agencies, some mechanical, others electromagnetic in origin. Features of mechanical and electrical design and construction which give rise to these agencies are discussed. The general character of the vibration which each agency produces is explained, as well as how different agencies combine to produce the resultant machine vibration. Where excessive vibration is encountered in the field, methods are outlined for ascertaining the major agencies responsible, so that corrective modifications may be made which will be effective in reducing the resultant vibration. These methods are applied to motor generator sets driven by two-pole induction motors to ascertain the cause of a particular type of vibration characterized by the vibration amplitude increasing and decreasing in uniform cycles twice during each revolution of motor slip. In this way the agencies which give rise to this particular type of vibration and how they may be controlled to keep the resultant vibration to a satisfactory minimum are explained.

44-170—High-Voltage Compressed-Gas Power Transformers; *H. M. Hobart* (*F '12*). *15 cents.* Proposals made at various times by H. J. Ryan, P. N. Nunn, A. A. Boelsterli, H. H. Skilling, and others, and important original suggestions of colleagues, notably W. W. Lewis and G. B. Warren, have been fitted together in the present paper into a high-voltage compressed-gas system which embodies features required by the modern needs of the electric-power industry. Of such is the provision, without incurring fire hazard, of the great economies of load-center operation at indoor locations in industrial plants. The system also provides decreased weights and costs of power transformers in general as well as longer life and greater capacity for sustained overloads. The proportion of the cost of transmission systems which is represented by the transformer outlay would be lessened very considerably by the employment of designs for higher periodicities of 600 cycles or more. Such periodicities cannot be used in long-distance overhead transmission lines because of corona, but it is proposed to associate the use of high periodicity with transmission conductors located in underground pipe lines containing a suitable gas at such a compression as to raise adequately the ionization limit. By means of such a system, using voltages greater than would be practicable with overhead lines and also using some such periodicity as 600 cycles, stable transmission can be provided for greater amounts of power than heretofore and for transmission over greater distances.

Electric Welding

44-101—Rating of Electric Equipment Under Intermittent Load; *Myron Zucker* (*M '36*). *25 cents.* The duty-cycle method customarily used in rating resistance-welding equipment for intermittent load is satisfactory for some applications, but leaves much to be desired in logic and frequently in accuracy. For a given piece of apparatus it can be justified only under continuous repetition of fast cycles. Usually, however, cycles are long or are broken up into groups. Then use of "duty cycle" as a guide sometimes overloads equipment and sometimes calls for excess capacity—which means unnecessary investment and higher costs. This paper studies ratings under a wide range of periodic heating cycles and explains how the rather arbitrary "maximum averaging time" limit may be removed. It derives relations for long and for short cycles, for a limited number of repeats, and for continuous application. In short, it provides a straightforward method for finding the temperatures reached within equipment that is carrying periodic load. Tests on an interleaved low-voltage resistance-welding cable substantiate this analysis.

44-105—The Design of Low-Voltage Welding-Power Distribution; *C. A. Adams* (*F '13*), *J. R. Fletcher* (*A '36*), *A. C. Johnson* (*A '42*). *30 cents.* This paper is an effort to state clearly, and to present a solution for, the problems encountered in the design of one of the vital constituents of a-c resistance-welder power supply—the low-voltage feeder. The scope of the paper is much wider, however, since the determination of design loads from the probability standpoint for the purpose of determining maximum allowable impedance and expected temperature rise, is a problem encountered in the design of all equipment common to a number of resistance-welding installations. The topics considered in the paper are:

1. Definition of voltage regulation as it applies to resistance-welding equipment.

2. Establishment of a criterion of good voltage regulation as defined.

3. Application of the theory of probability to the determination of maximum tolerable impedance and minimum copper section consistent with safe operating temperature.

ductive kilovars drawn by the load. The advantages of the various types of control and the choice of the number and size of capacitor steps to be switched are fully discussed.

Instruments and Measurements

44-161—A Resonant-Cavity Method for Measuring Dielectric Properties at Ultra-high Frequencies; *C. N. Works (A'40), T. W. Dakin, F. W. Boggs. 25 cents.* A re-entrant cylindrical cavity has been adapted to measure the dielectric constant and power factor of small disk samples of insulating materials. The disk of dielectric is placed between the flat ends of the cylindrical posts which form the re-entrant part of the cavity. The circuit is analogous to a less than one-quarter wave-length section of air-filled coaxial transmission line shorted at one end and ending in a capacitor with dielectric at the other end. This cavity with the dielectric inserted is brought to resonance by tuning the frequency of a loosely coupled oscillator. The power factor of the dielectric is determined from the breadth of the resonance curve, and the dielectric constant is obtained by removing the disk of dielectric and decreasing by a measured amount the separation of the flat ends of the re-entrant posts until resonance again is obtained at the same frequency as previously. The precision differential screw for varying the extension of the re-entrant post and other mechanical details are described. Electrical coupling and detecting methods also are discussed as well as the theory of the measurements. Each individual cavity can be utilized only over a frequency range of about 1.5 ratio from lowest to highest frequency. Therefore, several different-sized cavities would be required to cover a range of frequency from 50 to 1,000 megacycles. An accuracy of ± 0.00005 in tan δ and ± 1 per cent in dielectric constant may be obtained in routine measurements. Because the cavity has a very high $Q(>2,000)$, it is much more sensitive to low-power-factor dielectric samples than any conventional coil and capacitor resonant circuit. Operation of the apparatus is simple and rapid and very similar to the susceptance variation technique now used at lower radio frequencies.

Land Transportation

44-92—Modern Motive Power for Sorocabana Railway; *R. L. Chapman (M'30), O. K. Kjolseth. 15 cents.* The 20 electric locomotives being furnished to the Sorocabana Railway are the largest and most powerful 3,000-volt d-c meter-gauge units built to date. They weigh 286,000 pounds with 238,000 pounds on drivers, have a continuous rating of 1,910 horsepower, and will handle passenger, freight, and mixed trains on the 87-mile double-track mountainous section between São Paulo and Santo Antonio at a scheduled speed of 35 miles per hour for passenger, and 30 miles per hour for freight and mixed trains. The running gear consists of two three-axle driving trucks, and two single-axle radius bar guiding trucks. The truck frame, cab underframe, and cab are of welded construction, and incorporate throughout the use of fabricated subassemblies. The six traction motors are built to operate two in series on 3,000 volts and are of the commutating-pole force-ventilated type with antifriction bearings. Axle-suspension bearings are waste-packed and oil-lubricated. Single reduction gearing is used. A total of nine running steps in motoring is obtained by series, parallel, and reduced field combinations. Regenerative braking also is provided. The locomotives have two operating positions—one in each end.

44-96—Economics of Trolley-Coach Operation; *G. M. Woods (M'43). 15 cents.* The trolley coach is receiving considerable attention in the field of city transit as a result of its ability to increase patronage and operate at low cost. Its proper field of economic application lies between the fields of the street car and the motor bus. There are now 3,500 trolley coaches in operation in the United States and Canada. In 1943 they carried 8.7 per cent of all transit passengers. In the past 15 years many improvements have been made in the design of the electrical equipment of trolley coaches and in the overhead line material. These improvements have contributed to economy of operation and to the quality of the service. Material extensions of trolley coach service in the postwar period now are being planned by properties which have broad experience in their operation.

Marine Transportation

44-142—Modern Cargo-Winch Control for Use on Victory Ships; *F. H. Holt. 20 cents.* After discussion of the operating characteristics required for the electric driven cargo winch, the manner in which these characteristics may be obtained by the use of a properly designed motor control is outlined. The power circuit used for each operating point and the reason for its use is given as well as such interesting features of the control circuit as the explanation of the means by which both rapid acceleration of a load and smooth deceleration of a load from high speed may be obtained. The problems encountered in incorporating the control equipment in a waterproof enclosure mounted on the side of the winch are explained. The design and testing of the ventilated resistor located in the waterproof enclosure and the method of selection of the thermal switch to protect the resistor are reviewed.

44-159—Fault Protection on Shipboard A-C Power-Distribution Systems; *H. G. Rickover (Application pending), P. N. Ross. 30 cents.* Because of the upward trend in electric-power requirements on shipboard and the consequent growth in size, importance, and complexity of the power system, the application of fault protective devices has become a major factor in designing shipboard power-distribution systems. In particular, greater emphasis must be placed on the analysis of switching transients, fault currents, and the co-ordination of the various protective devices to ensure adequate protection combined with maximum reliability and continuity of service. Conventional methods of securing fault protection on low-voltage a-c systems have a number of shortcomings in meeting the requirements of marine service. Particularly outstanding in this respect are the limited usefulness of relays and the fact that oil-film time-delay dashpots commonly provided on low-voltage air circuit breakers are incapable of providing selective operation under fault conditions. A new direct-acting circuit breaker overcurrent trip device having characteristics suitable for fault protection on shipboard is described in the paper together with the principles and methods involved in the application of protective devices and calculation of fault currents.

Power Generation

44-98—The Summation of Load Curves; *R. F. Hamilton (M'18). 25 cents.* Wartime conditions offer engineers a challenge to utilize equipment to the utmost and to rearrange capacities according to needs. Peacetime economic controls no longer govern. This paper develops methods for computing load; the addition of loads which are similar except for timing; the addition of loads with various load factors; probability elements as applied to consumers' habits; the effect of peak time-concentration and load changes on the coincidence factor and system peaks; demand factors for composite loads including those for military establishments. Mathematical formulas are developed from fundamental elements of load curves and applied to typical problems.

44-106—The Effect of Weather on the System Load; *H. A. Dryar (M'43). 30 cents.* An accurate estimate of the daily peak load is essential to the reliable and efficient operation of an electric system. Daily peak variations usually reflect weather conditions. If any phase of the weather is excluded from the estimate, there may be a deficit in the operating capacity scheduled. The system load usually has two components. One, a fixed quantity, reflects business activity. The other, a variable quantity, the effect of weather. Correctly weighting this variable quantity promotes greater accuracy in load estimating. Occasionally another component indicates public response to broadcasts of unusual interest. This differentiation aids in assessing unusual load variations and determining their cause. To supplement the official weather forecast, existing weather conditions are weighted by the load dispatcher two hours before peak time and a final estimate made. If there is an error in the load estimate, its cause probably will be immediately apparent in changing weather conditions.

44-107—Conditions Controlling the Economic Selection of Prime Movers; *B. G. A. Skrotzki. 30 cents.* This paper attempts to clarify the effect of various controlling conditions on the magnitude of the evaluation constants used to select the optimum prime mover to be added to a system with a growing load. A hypothetical load has been set up which is assumed to grow at a known constant rate. By fixing on a policy of equal-sized units with two units being installed reserve and one unit operating reserve regardless of load magnitude, the progress of the individual generating units from the base to the top of the load curve can be studied readily. With the fundamental mechanics of the problem delineated the effects of unit availability, unit life span, rate of load

growth, load cycle, load factor, unit capacity, and system reserve policy are analyzed. From this analysis certain principles are apparent. Among the most important are:

1. Historical data of past and present prime mover experience are of very limited value.

2. Evaluation constants for future prime movers are not fixed in magnitude and must be redetermined from time to time for each individual system.

Having demonstrated the relative importance of the various controlling conditions this work concludes with a recommended procedure for determining the evaluation constants for any practical case.

Power Transmission and Distribution

44-114—The Measurement of Lightning Currents in Direct Strokes; *G. D. McCann (M '44). 20 cents.* The magnitude and wave shape of the discharge currents from 46 direct strokes have been measured during a five-year period at 25 direct-stroke recording stations on structures ranging in height from 75 to 585 feet. Measurements have been made with instruments capable of recording the wave front and tail of the high-current peaks and the low-magnitude continuing currents to as low as 0.1 ampere. Photographs have been made with special lightning cameras of 138 strokes to open ground and 22 cloud-to-cloud discharges. Data are given on the frequency with which objects of various heights are struck by lightning and the effect of height upon the character of the discharge. The principal characteristics of the lightning currents are summarized and several unusual recorded conditions are noted. Probability curves are given on the range and frequency of occurrence of the various stroke characteristics including polarity, total charge, crest current, wave front, time to half value, and duration.

44-115—Transmission - Line Electric Loadings; *S. B. Crary (M '37). 25 cents.* The electrical loading of transmission lines depends upon many factors worthy of review. Transmission systems by the use of quick switching, relaying, and modern design practices have overcome their stability limitations to a very considerable extent. This progress indicates the possibility of further increasing transmission-line loadings. This paper is devoted to discussion of real and reactive losses and stability limits of transmission lines from 50 to 300 miles in length, with a rather complete discussion of the characteristics of the 100-mile line which was taken as an important representative length for the transmission interconnections now existing. The real and reactive and their incremental losses are given in terms of dimensionless quantities which are applicable for lines of any length and voltage. Low resistance conductors are shown to have additional advantages beyond that of reduced real power losses, such as increased stability limit, reduced reactive kilovolt-amperes required for transmission, and a more equal distribution of the reactive kilovolt-amperes requirements between sending and receiving ends.

44-116—Ring Buses for Generating and Transmission Stations; *E. L. Michelson (A '37), J. P. Galassini (A '38). 20 cents.* Changes in bus requirements have led to the adoption of the ring bus as the standard bus installation in the generating and distributing stations of a large midwestern power system. The first bus layouts in this power system employed the straight-line bus but, because of changes in the methods of system operation, improved quality of equipment, and other requirements, the ring bus was found to have certain desirable features. The paper describes the electrical connections and the operating characteristics for the various forms of the straight-line bus and ring bus. It shows why it is advantageous to use the ring bus from the viewpoints of

1. Flexibility of connections.
2. Ease of providing relay protection.
3. Simplicity of maintenance.
4. Economy in investment.

This paper also contains the results of studies investigating the application of the ring bus to high-voltage transmission terminals.

44-117—Capacitor Installation at Newport News; *V. R. Parrack (M '31), E. L. Harder (M '41). 25 cents.* To meet a predicted reactive load requirement of approximately 15,000 kilovars, a large capacitor bank was installed at Newport News. This paper outlines the considerations involved in selecting the static capacitor and determining its novel design features. The 10,500-volt capacitor bank was made up of low-voltage outdoor pole-type units which could be used later in the distribution system. It was divided into five sections with manual switching for control of voltage. Tests were made after installation to check the adequacy and operating characteristics of the installation with regard to regulation, inrush currents, voltages during switching, and effect on wave shape. The underlying theories of these phenomena are reviewed briefly in the paper to provide a background for interpretation of the various test results presented. Tables, curves, and formulas for predicting inrush current magnitudes and frequencies and voltages encountered during switching are given. In general, the tests verified the ability to predict the several performance characteristics and provided useful empirical data on regulation. Inrush currents and voltages during switching were well within the limits of proper application. Harmonics were not seriously increased. The positive results of these tests provide a satisfying bench mark on the road to larger capacitor installations in single banks.

44-118—Capacitors, Condensers, and System Stability; *J. W. Butler (M '38), T. W. Schroeder (M '44), W. Ridgway (A '41). 30 cents.* This paper reports a study comparing the performance from the stability standpoint of a system using a large capacitor bank with that of the same system using a synchronous condenser of the same rating at the same location. Two general types of systems were studied, the so-called "interconnected" and the isolated or "noninterconnected." For the noninterconnected system, the effects on the transient stability of the hydroelectric station inertia, transient reactance, fault-clearing times, and so forth, are determined for either type of kilovar source of various ratings (condenser or capacitor) located at the receiving end. The effect on steady-state stability of supplying kilovars in the load areas is also determined. For the interconnected system, the effects on the transient-stability limits of the relative sizes of the two systems and the fault-clearing times, for either type and rating of intermediate kilovar source, are determined. The steady-state limits are also investigated. In general, it is shown that the difference between the effects on transient and steady-state stability of large capacitor banks and synchronous condensers is small.

44-119—A Method of Approach to the Consideration of Power-Distribution-System Costs; *O. B. Falls, Jr. (A '39). 20 cents.* The purpose of this paper is to present a generalized method of approach to the consideration of power-distribution system costs for various combinations of conditions when considering collectively the costs of each of the three basic elements which make up the so-called distribution system. These elements are:

1. The subtransmission circuits supplying the distribution substations.
2. The substations which transform from the subtransmission to the primary voltage.
3. The primary distribution system.

It has been found that consideration of the cost of any one of these parts without reference to the others may lead to erroneous conclusions as to the best over-all system from a cost standpoint. That is, the use of the minimum-cost design for one part may require expenditures for the other parts resulting in an over-all system cost higher than that necessary if all parts had been reviewed jointly and designs evaluated on an over-all basis. This kind of approach, wherein all elements of the system are included, is believed to be one which will give a complete picture of system costs.

44-130—Impulse Strength of Insulated-Power-Cable Circuits; *Herman Halperin (M '26), G. B. Shanklin (M '29). 30 cents.* This paper has been prepared at the request of the cable working group, AIEE committee on power transmission and distribution, to form an engineering basis for coordinating cable circuits with other equipment with regard to their ability to withstand transient overvoltages. Recommendations are given for safe withstand-impulse voltage of cables and accessories of various types. These are derived from co-ordinated analysis of all available published and unpublished data as well as some new test results. The significance of this information is discussed from the standpoint of overvoltages due to lightning and switching to determine when protective measures are necessary. Standard methods of impulse tests on cables are recommended.

44-131—Cyclic Movement of Cable—Its Causes and Effects on Cable Sheath Life; *C. S. Schifreen (M '43). 30 cents.* The relationships between loading, conductor-temperature changes, movement in manholes and ducts, and sheath life of paper and lead cable are discussed on the bases of operating experience, field surveys, and laboratory tests. The paper evaluates the factors re-

sponsible for the large percentage of non-inherent failures attributable to the physical proportions of underground structures on a large mileage of 15-kv three-conductor belted cable. The tests and operating experience indicate that unsatisfactory sheath life can result from daily cyclic movement of cable, although it may be operating at temperatures allowed in standard cable specifications. Modern paper insulation can withstand these temperatures safely as reflected in the relatively few inherent failures. Snaking of cable in ducts may impose severe cyclic strains and become the determining factor for optimum sheath life. Based on these tests, a method was developed for computing sheath life for given cable offsets and movements at the duct mouth.

44-132—An Investigation of the Relationship Between Temperature and Movement of Cables in Ducts; *C. T. Nicholson, T. J. Brosnan (M '34). 15 cents.* This paper describes the field tests which were made to determine the relationship between cable temperatures and cable movement in the manholes in an underground cable installation in Buffalo, N. Y. The special equipment and the testing procedure are described, and the test measurements are given in the paper. The results of the tests indicate that, in the area where the tests were made and for average cable section lengths, the practical operating factor is about one millimeter of realized longitudinal expansion per degree centigrade increase in sheath temperature. The test results suggest an explanation of how the cable expansion develops during temperature changes from different causes.

44-133—Gas-Filled Cable Research and Experience; *G. B. Shanklin (M '29). 15 cents.* Operating experience for the past five years with low, medium, and high-pressure gas-filled-cable installations is briefly outlined. Research and test data on gas-filled cable are presented and analyzed. Initial ionization starting voltage as a function of gas pressure ranging from atmospheric to 225 pounds per square inch, is compared with theoretical results and the significance of this starting voltage as related to practical gas-filled-cable design is explained. Long-time load-cycle endurance tests on gas-filled cable, covering a wide range of impregnating-compound viscosities, are presented, and the self-grading and self-healing properties of gas-filled cable are shown to be related to the viscosity of the impregnating compound. These beneficial properties increase in efficiency with decrease in viscosity, and the corresponding increase in mobility of the impregnating compound as a result of the compound's being drawn into voids and other critical locations by the electrical stress field. An optimum range of compound viscosities for best all-around results is demonstrated.

44-134—Operation of Low-Pressure Gas-Filled Cable; *C. T. Hatcher (M '37). 15 cents.* In papers presented before the AIEE in 1939 and subsequent years the theoretical aspects of paper-insulated cable utilizing gas as a pressure medium were discussed. Extensive laboratory test data were presented indicating the expected life of this type of cable. This paper presents factual data on the actual operation of low-pressure gas-filled cable of various types on the system of a large utility. The operating record for five years is presented and appears to substantiate previous laboratory data. The paper is the most comprehensive treatment of the subject pertaining to operating problems and experience yet published.

Protective Devices

44-93—Current-Transformer Output and Application Charts; *R. Koller (A '43). 15 cents.* In recent years a great deal of effort has been spent on the simplification of characteristic curves for multiratio bushing-type current transformers for relaying service. This paper describes a simplified chart from which the ratio error can be determined for any value of primary current, any number of secondary turns, and any value of secondary burden. The volt-ampere output of bushing-type current transformers at low primary currents is small and, in order to obtain optimum performance of relays, careful tuning between transformer taps and secondary burden is required. The volt-ampere–output characteristics are analyzed and a simple application chart is developed for tuning of relays and transformers. The use of the chart is explained in connection with various examples applied to commonly used relaying circuits.

44-97—Fusing Practices on Distribution Systems—II; *J. S. Parsons (A '27), J. M. Wallace (A '41). 15 cents.* Part I, recently presented, described the fusing practices now in use on about 150 systems operating below 5 kv. The present paper contains data gathered from the same operating companies on systems between 5 and 15 kv. Transformer fusing practice is tabulated for different circuit conditions. Charts showing the minimum size fuse link used and the maximum number of sectionalizing fuses also are given.

44-102—A Pneumatic Mechanism for Outdoor Oil Circuit Breakers; *L. J. Linde (A '39), E. B. Rietz (A '42). 15 cents.* The power required to operate the contacts of a circuit breaker is a function of its operating speed. The high operating speeds of modern tank-type oil circuit breakers often demand power beyond the capacity of existing control power sources. This power demand may be reduced very considerably if energy storage is used at a circuit breaker location. This paper describes the use of such stored energy in a compressed-air pneumatically trip-free mechanism for outdoor oil circuit breakers. Its simple design and low power demands add to its reliability and simplify the problems of application. Alternative methods of energy accumulation are discussed and the operating characteristics of the more usual prime movers for circuit breaker operators are briefly compared.

44-104—Bibliography of Relay Literature, 1940–43; *Interim report by the working group of the relay subcommittee of the AIEE committee on protective devices. 30 cents.* This report lists all important articles on the subject of protective relaying published from 1940 to 1943 inclusive in the AIEE *Transactions* and *Electrical Engineering* as well as most of the chief publications of the world. Previously this report has been available only to the members of the relay subcommittee in annual reports and to the general public only at ten-year intervals. However, the consensus of the subcommittee was that the urgency of the relay problems brought about by the war emergency makes it desirable to have this information more generally available at the present time. This report will supplement the paper, "Bibliography of Relay Literature, 1927 to 1939," published in July 1941 by the Institute.

44-135—A New Carrier Relaying System; *T. R. Halman (M '43), S. L. Goldsborough (M '43), H. W. Lensner (A '43), A. F. Drompp. 15 cents.* The many advantages of a single relay for complete phase and ground-fault protection of a transmission line have been realized in modern pilot-wire relays. By using the same basic principle of comparing single-phase quantities proportional to currents at the two ends of a line and using power-line carrier instead of a pilot wire, a new relaying system has been developed which combines the simplicity of pilot-wire protection with the versatility of carrier. An electronic trigger circuit is employed to provide half-cycle pulses of carrier-frequency energy from both ends of the line. These pulses are received at the opposite ends and compared with the phase position of the local single-phase quantity to determine whether an internal or external fault exists. An intermittent carrier system is used so that the carrier channel is available for auxiliary functions. Laboratory and field tests have proved the dependability of the new system.

44-157—Protection of Large D-C Rotating Machines by Means of High-Speed Circuit Breakers; *J. E. Housley (F '43), Otto Jensen (A '41). 15 cents.* A high-speed circuit breaker has been developed for the protection of large installations of d-c rotating machines. The circuit breaker is rated 7,500 continuous amperes and its contacts separated in 0.25 cycle (60-cycle basis). Short-circuit conditions of various d-c systems are described. The breaker utilizes a bucking-bar-holding-type magnet in combination with a roller clutch for its high-speed operation. The breaker and the modernization of a large rotary-converter station are described in detail.

44-158—Improved Selective Tripping of Low-Voltage Air Circuit Breakers; *C. P. West (M '28). 15 cents.* Selective tripping of low-voltage interrupting devices has been a problem since the first applications in which they were used in series. Arrangements, similar to those commonly used with high-voltage breakers, in which all interrupting devices have adequate interrupting ratings and selective opening is obtained by protective relays and by shunt-trip coils are best for insuring maximum continuity of power to all loads. However, this may require breakers which are relatively expensive compared with the power-consuming apparatus which they supply. Special cascaded arrangements defined by the National Electrical Manu-

facturers Association permit the use of low-voltage breakers in certain parts of circuits where they may be subjected to fault currents above their interrupting rating. But this use of less expensive breakers imposes a more restricted interrupting duty cycle and more maintenance is to be expected. Fully selective tripping for isolating breakers in cascaded circuits is not possible as main and group breakers must be allowed to open instantaneously if the current in the breaker next lower in the cascade exceeds its interrupting rating. This means a partial sacrifice of continuity of power to normal circuits. New integral mechanically delayed tripping devices for low-voltage breakers soon will be available. They will have nearly constant time–current tripping characteristics between the minimum and instantaneous operating values. This will improve the selective tripping of breakers in cascade circuits as back-up breakers can be kept closed safely until the current exceeds the interrupting capacity of the breaker next lower in the cascade. Delayed tripping at lower currents for selective action is provided. These tripping devices applied in circuits where all breakers have full interrupting capacity and short time ratings will give selective tripping equivalent to that now provided by shunt-trip coils and protective relays.

44-172—A New Frequency Relay for Power-System Applications; *J. L. Blackburn (M '44), H. J. Carlin (A '41). 20 cents.* Applications of frequency relays to power systems are described in which the relays are used to disconnect loads or system ties during emergencies. The requirements of the frequency relays for these applications are analyzed and a new relay which satisfies these requirements is described. This relay has adjustable time delay and a wide range of frequency settings with minimum temperature and voltage error.

Quality Control

44-113-ACO—The Applications of Statistics to Dielectrics; *C. M. Summers (M '39), K. E. Ross. 15 cents.* The application of statistics to insulations brings forth three important engineering problems which, heretofore, have not been given the consideration they deserve.

1. The specifications for a material must define adequately the characteristics of the insulating material.

2. A method of evaluating the material must be formulated to assure both the supplier and user that the material agrees with the specifications.

3. The material specifications must be translated into design practice.

The value of statistical terms and methods used in establishing a specification is stressed and control charts are suggested for determining whether or not the material adheres to the specifications. Illustrations based on the electrical and mechanical properties of an insulation paper are used. The transformation from a material specification to design practice and test objectives takes into consideration the time and temperature elements which affect the breakdown of insulation material. The use of statistical methods for determining the factors of safety is considered.

PERSONAL ••••

J. W. White (A '29) vice-president and general manager, Westinghouse Electric International Company, New York, N. Y., has been elected president and general manager. Mr. White first was employed by the Westinghouse Electric and Manufacturing Company, in Pittsburgh, Pa., Detroit, Mich., and Chicago, Ill., as sales engineer from 1907 to 1918. In 1918 he went to Havana, Cuba, as manager for the Westinghouse International Company. He was made general manager of the Westinghouse Company of Japan, Tokyo, in 1925 and managing director in 1927. From 1931 to 1936 he was stationed in Buenos Aires, Argentina, as managing director of the South American company. In 1936 he was appointed general manager and in 1937 vice-president. **G. H. Bucher** (M '24) formerly president of the International company becomes chairman of the board. Mr. Bucher is also president of the Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa. He was elected president of the International company in 1932 and president in 1934. He assisted in organizing the Westinghouse Electric Company of Japan in 1925.

Howard Maxwell (A '03, M '35) manager of the induction motor department, General Electric Company, Schenectady, N. Y., has retired. Graduating from the University of Kansas in 1900, he entered the General Electric Company as student engineer and in 1903 was transferred to the a-c engineering department. Entering the induction motor department in 1913 as superintendent he was made managing engineer in 1914 and manager in 1918. **M. H. Wells** (A '12) engineer in the induction motor department also has retired. Mr. Wells a graduate of Syracuse University entered the company as student engineer in 1902. In 1903 he became engineer in the a-c engineering department and in 1918 was named design engineer in the induction motor department.

M. M. Kenneally (M '29) formerly vice-president and sales manager, Porcelain Insulator Corporation, Lima, N. Y., is now associated with Joslyn Manufacturing Company. He also will act as special representative for the Porcelain Insulator Corporation.

R. L. Bertolacci (A '19) recently connected with the Federal Power Commission, Washington, D. C., is now on the electrical engineering staff of the California Railroad Commission, Los Angeles, with which he was associated as assistant engineer in 1934 and 1935.

J. S. Murray (A '21, M '31) chief electrical engineer, Follansbee (W. Va.) Steel Corporation, has been elected second vice-president of the Association of Iron and Steel Engineers for 1944. Mr. Murray held the office of national treasurer of that association in 1943.

L. J. Westin (A '35) formerly assistant manager of the boiler department, Day and Zimmermann, Inc., Philadelphia, Pa., has received the commission of lieutenant, junior grade, in the United States Naval Reserve, Ordnance Division.

W. L. Hiscox (M '35) formerly of the long lines engineering department, American Telephone and Telegraph Company, New York, N. Y., has been transferred to the general staff of the operating and engineering department.

W. R. Whitney (A '01) vice-president in charge of research, General Electric Company, Schenectady, N. Y., has been made an honorary member of the Electrochemical Society. Doctor Whitney was Edison medalist and John Fritz medalist for 1943.

R. H. Ranger (M '22) formerly major, Signal Corps, United States Army, has been promoted to lieutenant colonel and is now chief of the Corps' standards activities branch, Red Bank, N. J.

C. A. Atherton (M '42) formerly commercial engineer, Champion Lamp Works, Lynn, Mass., is on the staff of the development engineering department of the Reynolds Metals Company, Louisville, Ky.

G. S. Timoshenko (A' 33, M '39) associate professor of electrical engineering, University of Connecticut, Storrs, is engaged in research development for the Templetone Radio Company, Mystic, Conn.

H. W. Neblett (A '15, M '21) development and new design engineer, Inland Steel Company, East Chicago, Ind., has been elected a director of the Association of Iron and Steel Engineers for 1944.

R. E. Doherty (A '16, F '39) president of the Carnegie Institute of Technology, Pittsburgh, Pa., has been elected honorary member of the Engineering Institute of Canada.

De Gaspe Beaubien (A '07, M '21) consulting engineer, De Gaspe Beaubien and Company, Montreal, Que., has been elected president of the Engineering Institute of Canada.

T. H. Hogg (M '31, F '38) chairman and chief engineer, Hydro-Electric Power Commission of Ontario, Toronto, has been appointed to represent Canada on the public utilities committee of the United Nations.

C. T. Hurd (A '37) formerly salesman, Allis-Chalmers Manufacturing Company, Seattle, Wash., has been named central station specialist. Mr. Hurd has been employed by the company since 1935.

A. F. Duernberger (A '40) formerly commander in the United States Naval Reserve has been promoted to the rank of captain and is the commanding officer of the Naval Training School, Iowa State College, Ames.

J. W. Barker (M '26, F '30) dean, faculty of engineering, and professor of electrical engineering, Columbia University, New York, N. Y., recently received the honorary degree of doctor of laws from Union College.

J. H. Hagenguth (A '28, M '44) electrical engineer, General Electric Company, Schenectady, N. Y., has been appointed a member of the American Standard Association's committee on sphere gap standards.

W. P. Bear (M '22) retired engineer, Pacific Gas and Electric Company, San Francisco,

Calif., now is affiliated with the United States Maritime Commission, Oakland, Calif.

H. P. Liversidge (A '12, F '43) president, Philadelphia (Pa.) Electric Company recently was honored with the degree of doctor of science by Drexel Institute of Technology.

J. W. Gore (A '41) formerly foreman, electrical department, Bethlehem Steel Company, Baltimore, Md., has been made electrical superintendent.

R. C. Young (A '29) formerly sales engineer, Kuhlman Electric Company, Bay City, Mich., has been appointed assistant sales manager.

M. L. Waring (A '29, M '36) formerly captain, ordnance department, United States Army, is now a major.

OBITUARY

George Wilbur Hubley (A '94, M '00, F '26) consulting engineer, Louisville, Ky., died April 8, 1944. Born in Pittsburgh, Pa., May 9, 1870, he commenced his career in the student course of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., in 1887. In 1890 he became construction superintendent for the Citizens Traction Company, Pittsburgh. From 1893 to 1915 he was superintendent and chief engineer of the Louisville Gas and Electric Company and from 1915 to 1918 general manager and chief engineer of the Mechanics Heat and Light Company, Indianapolis, Ind. He was fuel administrative engineer in Louisville for the United States Fuel Administration in 1918. Since 1919 he had carried on a consulting practice in Louisville. He served as engineer with the Public Utilities Bureau of the City of Louisville from 1923 to 1935 and consulting engineer for the State Board of Charities and Correction from 1920 to 1924. He was a member of the American Society of Mechanical Engineers, the American Gas Association, the Sons of the American Revolution, and the Louisville Board of Trade.

Harry Gardner Wood (A '23, M '28) electrical engineer, Worthington Pump and Machinery Corporation, Harrison, N. J., died April 4, 1944. Mr. Wood, who was born August 2, 1891, in Jacksonville, Ill., received the degree of bachelor of science in electrical engineering from the University of Illinois in 1914. He entered the graduate student course of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., in 1914 and in 1915 was transferred to the switchboard section. He was made switchboard expert for the company's New York (N. Y.) District office, in 1916 and except for 17 months service with the United States Army remained in that position until in 1922 he was placed in charge of the switchboard section. He was named consulting engineer in 1923 and district engineer in 1927. In 1931 he joined the electrical sales department of the Worthington Pump company as consultant. He was a member of the Electrical Association of New York.

H. W. Hough (A '08, M '13) vice-president and general manager, Cleveland (Ohio) Electric Illuminating Company died recently. Mr. Hough was born January 20, 1885, in Baltimore, Md., and entered the electrical field in 1902 when he was employed by the Consolidated Gas and Electric Light and Power Company, Baltimore, for which he did testing, drafting, construction, and substation layout. From 1907 to 1910 he was chief electrician for the Norfolk (Va.) and Southern Railroad. In 1910 he joined the Cleveland Electric Illuminating Company and was made assistant to the chief electrical engineer in 1914. After a period of service as captain in the Engineers Corps of the United States Army, he returned to the company in 1919 as research engineer. He was appointed assistant to the president in 1923 and associate general manager in 1930. In 1934 he became vice-president and general manager.

Maxwell Henry (M '32) associate professor of electrical engineering, school of technology, College of the City of New York, N. Y., died April 7, 1944. Born in New York City, December 26, 1897, Professor Henry was graduated from the College of the City of New York in 1924 with the degree of bachelor of science. He had obtained a master electrician's license in 1918. In 1924 he was appointed instructor in electrical engineering at the College of the City of New York and was made assistant professor in 1930. In 1940 he became associate professor. He was a consultant for the New York State Civil Service Commission and one of the designers of the new Hunter College and Queens College buildings in New York City.

Victor Emmanuel Northup (A '39) superintendent of distribution and transmission, Scranton, (Pa.) Electric Company, died February 4, 1944. He was born November 20, 1888, in Glenburn, Pa. He worked as oiler and switchboard operator for the Atlantic City (N. J.) Electric Company in 1906 and 1907 before joining the Scranton Electric Company in 1907 as turbine and switchboard operator. He became substation operator in 1908 and meter tester in 1909. He served as district representative for the company at Archbald, Pa., from 1910 to 1912 and in 1912 was made service inspector and field engineer. He was appointed distribution and transmission engineer in 1922 and superintendent of distribution and transmission in 1929.

Edwin Richter Pearson (A '06, M '12) retired electrical engineer, Portsmouth, N. H., died recently. Mr. Pearson was born February 6, 1863, in Portsmouth, and was graduated from Massachusetts Institute of Technology in 1888. He was associated with the General Electric Company throughout his engineering career. He was employed as engineer in the transformer department in Lynn, Mass., from 1890 to 1895 and in Schenectady, N. Y., from 1895 to 1908. Transferred to Pittsfield, Mass., in 1909, he continued in the transformer department. In 1917 he was named consulting engineer and in 1922 he returned to Schenectady as electrical engineer. He retired in 1934.

J. B. Smith (A '24, M '33) assistant superintendent of electric production, Southern Indiana Gas and Electric Company, Evansville, died recently. Born in Glasgow, Scotland, October 21, 1893, Mr. Smith attended the West of Scotland Technical College. After serving in World War I, he was made electrical engineer in charge of station and distribution, Cia. de Electricidad, Punta Arenas, Chile. From 1922 to 1924 he represented Henley's Telegraph Works, Company, Ltd., London, England, as electrical sales engineer in Mexico. He entered the employ of the Central Illinois Light and Power Company, Peoria, in 1924 and joined the Southern Indiana Gas and Electric Company in 1928.

MEMBERSHIP

Recommended for Transfer

The board of examiners, at its meeting on May 18, 1944, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Allen, T. H., president, Board of Light, Gas and Water Commissioners, Memphis, Tenn.
Chandler, R. B., general mgr., Port Arthur Public Utilities Commission, Port Arthur, Ont., Canada
Giroux, C. H., special asst. to chief of engineers, U. S. War Dept., Washington, D. C.
Knight, Norman, chief engineer, western area, Bell Telephone Co. of Canada, Toronto, Ont., Canada
Lewis, F. M., senior engineer, U. S. Army Engineers, Bonneville, Oregon
Lindsay, R. W., vice-president, Mountain States Tel. & Tel. Co., Denver, Colo.
McCormack, J. E., asst. outside plant engr., Consolidated Edison Co. of N. Y., Inc., New York
Reid, C. R., general supt., Shawinigan Water & Power Co., Montreal, Que., Canada
Starbird, L. C., transmission and protection engr. for Texas, Southwestern Bell Telephone Co., Dallas, Texas
Wulfing, H. E., system planning engr., Commonwealth Edison Co., Chicago, Ill.

10 to grade of Fellow

To Grade of Member

Allen, W. M., Engr., Pacific Tel. & Tel. Co., Portland, Ore.
Ashmead, H. E., electrical engr., Naval Ordnance Lab., Washington, D. C.
Auld, W. F., chief engr., Lincoln Electric Co. of Canada, Ltd., Leaside, Ont., Canada
Bastedo, E. H., contract elec. engr., Anaconda Wire & Cable Co., Hastings-on-Hudson, N. Y.
Bement, D. L., vice-president, Northern Indiana Public Service Co., Hammond, Ind.
Blaine, L. J., asst. to vice-president, Dallas Power & Light Co., Dallas, Texas
Boesen, P. J., traction engr., City of Chicago, Chicago, Ill.
Buchanan, H. F., application engr., General Electric Co., Chicago, Ill.
Butterworth, P. T., division head, Boston Edison Co., Boston, Mass.
Chapin, S. L., elec. engr., Sargent & Lundy, Chicago, Ill.
Clark, W. R., electrical research engr., Leeds & Northrup Co., Philadelphia, Pa.
Cogbill, B. A., designing engr., General Electric Co., Pittsfield, Mass.
Calvin, A. D., transmission engr., Southwestern Bell Telephone Co., Dallas, Texas
Crosby, P. W., senior engr., Philadelphia Electric Co., Philadelphia, Pa.
Curtis, A. E., asst. supt. of transmission lines, The Shawinigan Water & Power Co., Montreal, Que.
Delvin, R. B., chief of technical staff, United Shipyards, Ltd., Montreal, Que., Canada
Dunn, J. F., associate elec. engr., Tennessee Valley Authority, Knoxville, Tenn.
Ein, Sam, engr., Carnegie Illinois Steel Corp., Chicago, Ill.
Elliott, R. D., chief engr., Dallas Power & Light Co., Dallas, Texas
Erbe, J. R., steel mill and metal working engr., Westinghouse E. & M. Co., E. Pittsburgh, Pa.
Exner, D. W., design engr., Westinghouse E. & M. Co., Lima, Ohio
Frigon, Augustin, acting general mgr., Canadian Broadcasting Corp., Montreal, Que., Canada
Galassini, J. P., planning engr., Commonwealth Edison Co., Chicago, Ill.

Gore, C. W., chief engr., Clark & Wilson Lumber Co., Portland, Ore.
Gore, J. W., supt., elec. dept., Bethlehem Steel Co., Baltimore, Md.
Hampe, G. W., engr., Commonwealth Edison Co., Chicago, Ill.
Harris, Thomas, owner, H. S. Tittle Co., San Francisco, Calif.
Holder, Edward, supt. of metering, Shawinigan Water & Power Co., Montreal, Que., Can.
Jones, C. W., asst. elec. design engr., New England Power Service Co., Boston, Mass.
Jones, T. B., Lieut., U. S. Naval Reserve, Chicago, Ill.
Jones, T. L., plant extension engr., Southwestern Bell Tel. Co., St. Louis, Mo.
Knapp, E. W., system planning engr., Shawinigan Water & Power Co., Montreal, Que., Canada
Lancio, J. W., engg. dept., Hartford Electric Light Co., Hartford, Conn.
Martin, H. L., NW District Central Station Mgr., Westinghouse E. & M. Co., Chicago, Ill.
McDonald, D. J., foreign wire relations engr., Bell Tel. Co. of Canada, Montreal, Que., Canada
Michelson, E. L., supervising planning engr., Commonwealth Edison Co., Chicago, Ill.
Millington, J. W., research engr., Sun Oil Co., Beaumont, Texas
Morgan, N. L., cable design engr., Northern Electric Co., Ltd., Montreal, Que., Canada
Nixon, J. A., engr., Southern New England Tel. Co., New Haven, Conn.
Price, G. F., engr., Southeastern Underwriters Association, Atlanta, Ga.
Ringer, R. L., elec. engr., Allen B. DuMont Labs., Inc., Passaic, N. J.
Robinson, H. H., asst. regional utility engr., War Production Board, Dallas, Texas
Shaw, H. N., consulting engr., Erie, Pa.
Sellers, L. R., senior elec. engr., Tennessee Valley Authority, Knoxville, Tenn.
Steever, E. G., engr., General Electric Service Shop, Dallas, Texas
Vencill, G. J., hydraulic engr., Union Electric Co. of Missouri, St. Louis, Mo.
Webb, R. B., engr., Southwestern Bell Tel. Co., Dallas, Texas
Whaley, C. D., elec. engr., Sperry Gyroscope Co., Inc., Garden City, N. Y.
Wilson, H. R., Lieut., U. S. Naval Reserve, Cambridge, Mass.
Wolf, E. F., asst. to supt., Consolidated Gas Elec. Lt. & Pwr. Co., Baltimore, Md.
Wright, J. L., industrial sales engr., General Electric Co., Portland, Ore.

51 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Any member objecting to the election of any of these candidates should so inform the national secretary before June 30, 1944, or August 31, 1944, if the applicant resides outside of the United States or Canada.

To Grade of Member

Andrews, C. F., Ill. Northern Utilities Co., Dixon, Ill.
Baker, F. J., Elec. Pr. Board of Chattanooga, Chattanooga, Tenn.
Barnett, D. E., Memphis Light, Gas & Water Div., Memphis, Tenn.
Cerrillo, M., Mexican Gov., Mexico, D. F., Mex.
Clark, K. R., Austin Co., Cleveland, Ohio
Dahms, A. A., Allis-Chalmers Mfg. Co., Kansas City, Mo.
Dorsch, E. O., E. O. Dorsch Elec. Co., St. Louis, Mo.
Eberhardt, W. W. (Reelection), Alabama Pr. Co., Birmingham, Ala.
Eltgroth, G. V., Bendix Aviation Corp., Towson, Md.
Fellows, F. C., H. Stevens Co., New York, N. Y.
Fitch, L. C., General Elec. Co., Pittsfield, Mass.
Gagen, J. M. (Reelection), Federal Pub. Housing Auth., New York, N. Y.
Gunnison, G., C. H. Stevens Co., New York, N. Y.
Havas, V., Austin Co., Cleveland, Ohio
Hillemeier, A. K., Mississippi River Pr. Co., Keokuk, Iowa
Johnson, K. C., Major, U. S. Army, Pine Bluff Arsenal, Ark.
Kinn, T. P., Westinghouse Elec. & Mfg. Co., Baltimore, Md.
Kline, C. M., Ajax Elec. Furnace Corp., Philadelphia, Pa.
Kwasky, A. J., Hurley Marine Works, Oakland, Calif.
Leavitt, A. J. (Reelection), Metcalf & Eddy, Engrs., Boston, Mass.
Leib, F. E. (Reelection), Copperweld Steel Co., Washington, D. C.
Matzenauer, J. H., St. Bonaventure College, St. Bonaventure, N. Y.
Mayo-Wells, W. J., British Air Comm., Washington, D. C.
McCann, C. F., New York State Elec. & Gas Corp., Elmira, N. Y.
Murphy, J. J. (Reelection), Westinghouse Elec. & Mfg. Co., Buffalo, N. Y.
Norwood, R. F., Chesapeake & Potomac Tel. Co. of W. Va., Charleston, W. Va.
Peterson, E. S., Jr., J. A. Jones Const. Co., Brunswick, Ga.
Potts, W. R., Atlantic Steel Co., Atlanta, Ga.
Prendergast, R. M. (Reelection), Canadian Gen. Elec. Co. Ltd., Ottawa, Ont., Can.
Ramsay, A. T. (Reelection), Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Rickover, H. G., Capt., U. S. Navy, Washington, D. C.
Snow, D. P., Standard Tel. & Cables, Ltd., Leicester, England
Rutherfurd, G. R. (Reelection), Southern Calif. Tel. Co., Los Angeles, Calif.
Stapleton, G. M., Ward Leonard Elec. Co., Mount Vernon, N. Y.
Strange, A. M., Boeing Aircraft Co., Seattle, Wash.
Stremel, R. A., Yuba Mfg. Co., Benicia, Calif.
Wright, H. R., Pacific Mills, Ltd., Ocean Falls, B. C., Can.

37 to grade of Member

To Grade of Associate

United States and Canada

1. North Eastern

Bronzo, J. A., Mass. Inst. of Tech., Cambridge, Mass.
Cafora, T. P., Radio Center Service, Bridgeport, Conn.
Collins, J. S., So. New Eng. Tel. Co., New Haven, Conn.
Eck, E., General Elec. Co., Pittsfield, Mass.
Fitch, W. M., Jr., General Elec. Co., Schenectady, N. Y.
Gunnoe, H. G., Jr., General Elec. Co., Schenectady, N. Y.
Howell, R. L., Central N. Y. Pr. Corp., Oswego, N. Y.
Jones, C. L., Jr., Central N. Y. Pr. Co., Utica, N. Y.
Larlton, V. C., Rudolph Wurlitzer Co., North Tonawanda, N. Y.
Phillips, M. T., U. S. Engineers, Buffalo, N. Y.
Priestley, K., Eastern Elec. Const. Co., Bridgeport, Conn.
Redman, E. M., Stromberg-Carlson Co., Rochester, N. Y.
Reifsnyder, J. G., General Elec. Co., Schenectady, N. Y.
Robbins, C. I., General Elec. Co., Schenectady, N. Y.
Shere, G. D., Raytheon Mfg. Co., Waltham, Mass.
Ward, J. T., Boston Edison Co., Boston, Mass.
Zchner, J. L., General Elec. Co., Schenectady, N. Y.

2. Middle Eastern

Bailey, R. C., Ohio Bell Tel. Co., Youngstown, Ohio
Debel, C. A., Naval Research Lab., Bellevue, D. C.
Duryee, P. A., Fisher Aircraft Div., Cleveland, Ohio
Dyer, C. E., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Feige, W. C., Jr., Cons. Gas Elec. Lt. & Pr. Co. of Balt., Baltimore, Md.
Foland, M. E., National Cash Reg. Co., Dayton, Ohio
Friedman, C., Ensign, USNR, Washington, D. C.
Gregory, J. A., C & P Tel. Co. of Wash., D. C., Washington, D. C.
Hennemeyer, C. A., Alliance Mfg. Co., Alliance, Ohio
Jones, E. E., Naval Ordnance Lab., Washington, D. C.
Kuester, D. W., Jr., U. S. Navy Yard, Washington, D. C.
Nicolai, R. C., Fenn College, Cleveland, Ohio
Olson, C. O., Jr., Naval Research Lab., Washington, D. C.
Rife, W. M., National Cash Reg. Co., Dayton, Ohio
Thaler, G. J., Johns Hopkins Univ., Baltimore, Md.
Vilchis, M. C., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
White, J. C., Penna. R.R., Wilmington, Del.

3. New York City

Andersen, C. J., Sanderson & Porter, New York, N. Y.
Barnes, R. F., Kellex Corp., New York, N. Y.
Brittain, G. H., Jr., Hamilton Radio Corp., New York, N. Y.
Hauss, F. T., Queens Borough Gas & Elec. Co., Far Rockaway, N. Y.
Hoffman, J. S., General Elec. Co., New York, N. Y.
Kuhnel, A. H., M. W. Kellogg Co., New York, N. Y.
Ledermann, F., Patent Attorney, New York, N. Y.
Leech, P. H., Jr., Kellex Corp., New York, N. Y.
Lernet, M. L., Westinghouse Elec. & Mfg. Co., Newark, N. J.
Lynn, F. L., Sperry Gyroscope Co., Lake Success, N. Y.
Meier, J. C., "Electrical World," New York, N. Y.
Neidig, F. J., North American Philips Co., New York, N. Y.
Schooley, C. E., American Tel. & Tel. Co., New York, N. Y.
Stenger, F. J., Columbia Univ. Airborne Instrument Lab., Mineola, N. Y.
Weaver, D. E., Elec. Storage Battery Co., New York, N. Y.

4. Southern

Bloom, T., Norfolk Navy Yard, Portsmouth, Va.
Elder, B. H., Ethyl-Dow Chemical Co., Wilmington, N. C.
Hoagland, J. W., U. S. Navy, Louisville, Ky.
Jones, G. L., Tenn. Eastman Corp., Oak Ridge, Tenn.
Lanier, W. J., Allis-Chalmers Mfg. Co., Memphis, Tenn.
Myers, C. S., Westinghouse Elec. & Mfg. Co., Atlanta, Ga.
Nelson, R. E., Tenn. Eastman Corp., Oak Ridge, Tenn.
Peltier, K. W., Tenn. Eastman Corp., Kingport, Tenn.
Pool, M. F. (Reelection), Tubize Rayon Corp., Rome, Ga.

5. Great Lakes

Adler, H. A., Commonwealth Edison Co., Chicago, Ill.
Barnes, T. F., Detroit Edison Co., Detroit, Mich.
Dammann, G. E. (Reelection), Commonwealth Edison Co., Chicago, Ill.
Feigal, R. S., Minneapolis Honeywell Reg. Co., Minneapolis, Minn.
Fitzgerald, J. S., Caterpillar Tractor Co., Peoria, Ill.
Freer, J. E., Reo Motors, Inc., Lansing, Mich.
Furst, U. R., Russell Elec. Co., Chicago, Ill.
Hempstead, K. F., Pub. Serv. Co. of Northern Ill., Waukegan, Ill.
Janssens, J. N., Intl. Automatic Elec. Corp., Chicago, Ill.
Kriz, A., Bureau of Engg., City of Chicago, Chicago, Ill.
LeBron, R. L., Jr., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Liggett, C. P., Commercial Solvents Corp., Peoria, Ill.
Lommen, R. M., Cutler-Hammer, Inc., Milwaukee, Wis.
Nealon, L. N. (Reelection), General Elec. Co., Fort Wayne, Ind.
Russell, L. T., Consumers Pr. Co., Jackson, Mich.
Toegrel, S., Radio Corp. of America, Indianapolis, Ind.
Weinhold, R. D., Allis-Chalmers Mfg. Co., West Allis, Wis.

6. North Central

Collier, J. E., Collier Elec. Co., Denver, Colo.
Rempel, E. H., Mountain States Tel. & Tel. Co., Denver, Colo.
Walters, E. T., U. S. Bur. of Reclamation, Seminoe Dam, Wyo.

7. South West

Bliss, W. J. (Reelection), Square D Co., Houston, Texas
Cardwell, L. H., Dallas Pr. & Lt. Co., Dallas, Texas
Collerain, J. F., Sr., Houston Pipe Line Co., Houston, Texas
Fewell, E. C., Union Elec. Co. of Mo., St. Louis, Mo.
Jenkins, J. M., Curtis-Wright Corp., St. Louis, Mo.
Lackey, R. W., Electrical Post Engineer Office, Jefferson Barracks, Mo.
Lyman, C. D., Kansas City Pr. & Lt. Co., Ottawa, Kans.
Maas, C. A., General Elec. Co., Dallas, Texas
Rademeyer, H. P., Curtis-Wright Corp., St. Louis, Mo.
Rembert, E. H., Pub. Serv. Co. of Okla., Tulsa, Okla.

8. Pacific

Chapel, F. G., Southern Calif. Tel. Co., Los Angeles, Calif.
Cunning, J. C. (Reelection), Bureau of Pr. & Lt., Los Angeles, Calif.
Derin, H. H., U. S. Navy, San Francisco, Calif.
Ford, P. D., U. S. Naval Drydocks, Hunters Point, Calif.
Jones, R. J., U. S. Navy Yard, Mare Island, Calif.
Jurwich, C. C., Southern Calif. Tel. Co., Los Angeles, Calif.
Schott, F. W., San Diego Gas & Elec. Co., San Diego, Calif.
Walters, W. T., General Metals Corp., Oakland, Calif.

9. North West

Bergdahl, C. R., E. I. DuPont de Nemours & Co., Richland, Wash.
Bjork, R. E., Montana Pr. Co., Great Falls, Mont.
Byers, E. C., Washington Water Pr. Co., Spokane, Wash.
Chambliss, H. E. (Reelection), Montana Pr. Co., Great Falls, Mont.
Daniels, C. C. (Reelection), Montana Pr. Co., Great Falls, Mont.
Heineck, W. A., Washington Water Pr. Co., Spokane, Wash.
McArthur, S. E., Montana Pr. Co., Great Falls, Mont.
McGee, T. W., Boeing Aircraft Co., Seattle, Wash.
Monroe, B. J., Montana Pr. Co., Great Falls, Mont.
Morton, H. A., Montana Pr. Co., Great Falls, Mont.
Neumann, W. R., Montana Pr. Co., Great Falls, Mont.
Nordeen, B. W., Montana Pr. Co., Great Falls, Mont.
Sheire, J. B., Montana Pr. Co., Great Falls, Mont.
VanNoy, T. A., Montana Pr. Co., Great Falls, Mont.
Wilson, R. M., Washington Water Pr. Co., Spokane, Wash.

10. Canada

Armstrong, H. D., Lieut., R.C.N. V.R., Toronto, Ont., Can.
Foulis, R. M., Dorval Airport, Dorval, Que., Can.
Harris, R. A., Canada Wire & Cable Co., Ltd., Leaside, Ont., Can.
Hogg, J. D., Montreal Engg. Co., Ltd., Montreal, Que., Can.
Little, J. A., Commonwealth Elec. Corp., Ltd., Welland, Ont., Can.
Orwell, A. E., Northern Elec. Co., Ltd., Montreal, Que., Can.

Elsewhere

Barrios-Morales F., D., Com. Federal de Electricidad, Mexico, D. F., Mex.
Carrion, A., A., National Rys. of Mex., Mexico, D. F., Mex.
Chellappa, T. R., Pykara Elect. System, Coimbatore, Madras, India
Elizondo N. A., Com. Federal de Electricidad, Mexico, D. F., Mex.
Garcia R., D. L., Mex. Gov. Defense Sec., Mexico, D. F., Mex.
Gutierres, S. F. J., National Powder Factory, Santa Fe, D. F., Mex.
Kiewek, C. J., Com. Federal de Electricidad, Mexico, D. F., Mex.
Lerch G., E., Com. Federal de Electricidad, Mexico, D. F., Mex.
Llubere Z., P., Com. Federal de Electricidad, Mexico, D. F., Mex.
Loubet V., E., Com. Federal de Electricidad, Mexico, D. F., Mex.
Mata, E. R., Mex. de Electricidad, Mexico, D. F., Mex.
Mayer O., C., CIA Mex. Maquinaria, Mexico, D. F., Mex.
Monterrubio B., I., Com. Federal de Electricidad, Mexico, D. F., Mex.
Otero O., J. F., Com. Federal de Electricidad, Mexico, D. F., Mex.
Peralta Diaz C., A., Ind. Unidas S. A., Mexico, D. F., Mex.
Rivera S., J., Contracting & Consulting Engr., Mexico, D. F., Mex.

Total to grade of Associate
United States and Canada 117
Elsewhere 16

OF CURRENT INTEREST

Clearinghouse for Technical Translations Established

A technical-translations clearinghouse has been organized recently to supply a focal service for photoprinted copies of articles translated from foreign scientific journals or periodicals. It is being operated as an extension of the auxiliary publication service of the American Documentation Institute with the co-operation of the Office of Alien Property Custodian.

Provision for such a service was undertaken at the suggestion of interested organizations which offered copies of their translations as a nucleus. Scientists, libraries, and research and industrial organizations possessing technical translations published in whole or part since 1940 are asked to deposit with the clearinghouse a typed ribbon copy or a good carbon of each translation now on file or to be published in the future. If only one copy of the translation is in existence that copy should be deposited, and the ADI will replace this with a microfilm or photoprint as desired. The clearinghouse is also soliciting information concerning existing public, institutional, and commercially available collections of such translations which should include the location of the collection, general description of the contents and the name and address of the person from whom the material can be requested.

A complete list of translations available from both the technical-translations clearinghouse and other existing reference pools will be compiled shortly for wide distribution. In order to avoid possible infringement of foreign copyright interests, the Alien Property Custodian, within specified limits, will vest such copyright interests and license the reproductions of such translations for general use and distribution.

Copies of translations and information pertinent to their availability should be addressed to the American Documentation Institute, 1719 N Street North West, Washington, D. C. Translations will be supplied upon order at the standard ADI copying-cost rate of one cent per page in microfilm and ten cents per page in photoprint, with a minimum charge of 50 cents.

Technically Trained Personnel Urged to Register With NRSSP

The National Roster of Scientific and Specialized Personnel, a civilian agency of the Government created in 1940 as a central registry for persons possessing professional and scientific qualifications, is responsible for the best utilization for the war effort of technically trained personnel.

In the light of recent Selective Service directives that will result in the induction of many thousands of professionally and scientifically trained young men under the age of 26, it is important that all qualified young engineers, chemists, physicists, geologists, mathematicians, and others be so registered. Those individuals who will enter the Armed Forces immediately should notify the Roster of the branch of service they are entering, the date and place of their induction, and, afterwards, their serial number.

Although the Roster has no responsibility as regards their assignment within the Armed Forces, it reports to the office of The Adjutant General, War Department, and to the Bureau of Navy Personnel, Navy Department, concerning the specialized training and qualifications of those of its registrants inducted into the Army or Navy. This information is used as an aid in determining the initial military assignment of the particular individual. Should it become necessary to withdraw a number of specialists from the Armed Forces in order to reassign them to important research or production work in civilian war industry, the Roster's records are sufficiently detailed to permit intelligent selection of qualified individuals in almost every specialized field, and probably it will be called upon to assist in any such assignment.

Initial registration or notice of any change in status should be addressed to the National Roster of Scientific and Specialized Personnel, 1006 U Street North West, Washington 25, D. C.

Inventors Council Poses Military Problems for Public Solution

The National Inventors Council has recently announced a new list of problems of present import to the armed services for which it is soliciting solutions. (For previous listing see *EE, Aug. '43, p. 380*). Included in the list are the following suggestions which may be of interest to electrical engineers:

1. A relatively simple gauge to measure the impulse of explosion blast. Its positive and negative phases should be determined separately but concurrently, and it would be desirable if the duration of each phase could be determined in some simple manner.

2. Removal of dissolved mineral matter from sea and brackish water by ionic-exchange process.

3. An instrument for the location and destruction of concealed enemy emplacements, pillboxes, and similar strong points.

4. Improvements in tank vision devices and control instruments. There is special interest in reducing space requirements and improving the performance of gyroscopic compasses.

5. Ingenious and simple decoy devices for the purpose of confusing and misleading the enemy.

6. Technical data as to strategic enemy targets such as chemical plants, explosive plants, power plants, and so forth.

7. A noiseless hand generator combined with a lightweight flashlight. The generator should be pumped at the rate of 40 revolutions per minute, and the light should start on the first pump and should be continuously brilliant.

8. Plumb bob type of generator to operate a light six-volt radio. The generator probably should be operated by a reel winding up and letting out the plumb bob.

Suggestions should be submitted to the National Inventors Council, Room 1313, Commerce Building, Washington 25, D. C., and should comprise a clear description of the proposal with such sketches or drawings as may be necessary.

Allis-Chalmers Creates New Division. Creation of a new research and gas-turbine development division of Allis-Chalmers Company, Milwaukee, Wis., under the management of J. T. Rettaliata, has been announced recently by R. C. Allen, manager of the company's steam-turbine department. Although all steam-turbine design and engineering-research activities will be conducted by the new division, its most significant work will be in the development of the much-discussed gas turbine. Previously the company has built nearly 30 gas-turbine units for oil refineries and currently is producing the aircraft supercharger version of the gas turbine. Doctor Rettaliata has specialized largely in gas-turbine research and development, and has received annual awards for the past three years from national engineering and scientific societies for his contributions to this field.

United States and Canadian Armed Forces Standardize Radio Tubes

To make possible interchangeability of tubes, common stockpiles, and use of standard nomenclature, and to eliminate dual inspection at manufacturers' plants, the United States Army and Navy and the Canadian armed services have authorized standardization of radio tubes, according to reports received from the Office of the Chief Signal Officer.

The recently approved specification for radio tubes is based on the use of Radio Manufacturers' Association and commercial type numbers, and derives from work begun early in 1942 by a joint Army–Navy committee. Before Pearl Harbor, each of the services had its own system of tube nomenclature which, in many cases, was unrelated to that of the RMA and other commercial type numbers. It is expected that the quality of the tubes will improve somewhat in the future, now that the manufacturer no longer is obliged to make the same type of tube meet slightly different specifications.

INDUSTRY . . . . .

WGN Conducts $10,000 Contest for Design of New Radio Theater

WGN, Inc., sponsors of the 720-kilocycle broadcasting station in Chicago, Ill., has announced a $10,000 prize contest for the design of a new air theater capable of seating 2,000 persons, to be constructed as soon as materials are available. As projected, it will be adaptable to both television and FM

broadcasting, and will be constructed in the heart of a new eight- or ten-story building to be erected by WGN as a complement to the prizewinning design.

Prizes for the winning designs, to be awarded by a group of WGN radio experts, will be distributed as follows: $5,000 for first prize, $2,500 for second prize, $1,000 for third prize, and 15 prizes of $100 each. Basic principles on which the contest is to be judged are, in the order of their importance, acoustics and utility, visibility, and beauty of design.

The stage should be approximately 60 feet square and capable of accommodating an orchestra of 75 pieces, a chorus of 40, and the principals of a musical cast. It should be adaptable for dramatic performance, and should allow for control rooms, flyloft, lighting equipment, and storage space. The auditorium may have one or two balconies, at the discretion of the designer.

$1,000 Annual Award Honoring Stanton Hertz Established

Creation of the Hertz Award, a tribute to Stanton S. Hertz (F '39) late vice-president and assistant to the president of the Copperweld Steel Company, Glassport, Pa., was announced at the annual convention of the National Rural Electric Co-operative Association held in Chicago, Ill., recently. It provides for a bequest in the amount of $1,000 to be presented annually, with an appropriate medal, to the person employed by a member Co-operative who, in the opinion of the award committee, has made the greatest technical contribution to the field of rural overhead-line design, construction, or maintenance during the preceding year.

The award was established by the Copperweld Steel Company, with whom Mr. Hertz was affiliated for about eighteen years, to commemorate "his significant engineering contributions to the progress of rural electrification in the United States." It will be bestowed for the first time at the 1945 convention of the NRECA. Recommendations for the honor shall be made to the award committee by the presidents of the operating Rural Electric Co-operatives, and a majority vote of the committee's membership, not yet announced, will determine the recipient.

Mr. Hertz was well known to the electrical industry for his studies on grounding problems and electric conductors. He served from 1936–41 as the first executive director of the Copper-Wire Engineering Association, and was one of the pioneers in the development of Copperweld-copper conductors for rural electrification. He died on February 17, 1943. For a more detailed biographical sketch of Mr. Hertz, see *Electrical Engineering*, April 1943, page 176.

KYW, KDKA, and WBZ Plan Television Broadcasting. Applications for licenses to install television broadcasting facilities as additions to radio stations KYW in Philadelphia, Pa., WBZ in Boston, Mass., and KDKA in Pittsburgh, Pa., as soon as critical materials become available, have been filed with the Federal Communications Commission by Westinghouse Radio Stations, Inc., L. B. Wailes, general manager of the company has announced. Establishment of the television stations will entail additions of new studios, transmitters, and other equipment to the company's radiobroadcasting stations in the three cities. The company is contemplating future televised programs of motion pictures and outdoor events as well as the existing studio shows. Television techniques and radio program sources are expected to lead naturally to broadening of the medium's usefulness.

Industry–University Research Project Established at Purdue

Establishment of a joint industry–education enterprise at Purdue University, Lafayette, Ind., for intensive training of graduate students in exploration of the field of heat transfer was announced recently by G. Stanley Meikle, research director of the Purdue Research Foundation, and A. A. Potter, dean of the Schools of Engineering.

Made possible by a $75,000 grant from Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., the five-year training and research program will be directed by George A. Hawkins of the Purdue University engineering faculty, who has been appointed Westinghouse research professor in heat transfer. Dr. Hawkins will select his research associates, to be known as fellows, and for their experiments the scientists will have access to the heat-transfer laboratory of the school of mechanical and aeronautical engineering and other University facilities. Dr. Max Jakob of the Illinois Institute of Technology will co-operate with Dr. Hawkins in the capacity of nonresident research professor.

Dielectric-Heating Research Begun at Columbia and Illinois

Laboratories for research into the basic principles and industrial applications of high-frequency heating have been established at Columbia University, New York, N. Y., and the Illinois Institute of Technology, Chicago, with the aid and support of interested corporations.

The laboratory for investigating high-frequency heating at Columbia University will be staffed by chemical engineers from the University and by scientists and technical experts from the Induction Heating Corporation, New York, N. Y. which has equipped the laboratory. The research program is under the direction of Arthur W. Hixson, professor and head of the University's department of chemical engineering and Philip W. Shutz, professor of chemical engineering. Everett K. McMahon, specialist in chemical engineering applications is in charge of the laboratory.

A similar $5,000 research project for the study of dielectric heating has been initiated at Illinois Institute of Technology, by the Chicago Molded Products Company. J. E. Hobson (M '41) head of the electrical-engineering department will supervise the electrical phase of the studies and E. J. Bicek, instructor in chemistry, the chemical phase. Bernard Parmet (Enrolled Student) and Arthur Kott, research assistants in electrical engineering and chemistry, respectively, have been awarded fellowships to carry on the project.

Already successfully employed in the dehydration of foods and in the setting of glue between plywood layers, dielectric heating is expected to be applied widely in such processes as the drying of lumber, soap, and ceramic materials and in the curing of rubber and the molding of plastics. Although the cost is still prohibitive for everyday use, high-frequency heating has been employed experimentally in cooking.

Welding Industry Symposium Published. "Welding Industry Symposium," a compilation of 23 technical papers covering diverse phases of welding, recently was issued by the Consolidated Reporting Company, New York, N. Y. Among the subjects discussed are welding techniques, safety and health, fundamental metallurgy, fabrication of tools by welding, repairing, and common welding problems.

M. E. Thompson Dies. M. E. Thompson, pioneer in the electrical industry and inventer, who helped develop the compensated generator, died April 5, 1944, in Ridgway, Pa. He was 80 years old. Mr. Thompson received the degree of bachelor of science from Cornell University in 1890. As assistant to Harris J. Ryan, professor of electrical engineering at Cornell University and later at Leland-Stanford University, he conducted tests on the first electric generator equipped with compensating windings, designed by Doctor Ryan. As a result of these tests Mr. Thompson designed in 1893 the ten-kilowatt 110-volt six-pole belted generator now displayed in the Edison Institute, Dearborn, Mich., which bears the inscription: "This is the first generator ever built having compensated winding and commutating poles." During World War I he was a pioneer in the development of electrical propulsion equipment for submarines of the United States Navy. Mr. Thompson previously had been chief engineer of the Elliott Company, Jeannette, Pa., and at the time of his death was employed by the company as consulting engineer. He was the oldest employee of the Ridgway division of the company.

OTHER SOCIETIES •

ASTM Forms Committee on Metal Powders and Their Products

A new standing committee on metal powders and metal-powder products, *B–9*, has been established by the American Society for Testing Materials to undertake the formulation of specifications and methods of tests for these materials. Technical representatives of leading producers and consumers of metal powders and their products are serving on the committee and its working groups,

with W. A. Reich, General Electric Company, Schenectady, N. Y., as chairman, and W. R. Toeplitz, production manager, Bound Brook (N. J.) Oilless Bearing Company as secretary.

Subcommittees, organized to consider immediately adequate tests and methods of evaluating essential properties of the powders and compacts, are listed with their chairman as follows:

1. *Nomenclature and technical data:* chairman; F. N. Rhines, Carnegie Institute of Technology, Pittsburgh, Pa.

2. *Metal powders:* chairman; D. O. Noel, Metals Disintegrating Company, Inc., Elizabeth, N. J.

3. *Metal-powder products:* chairman; R. P. Koehring, Moraine Products Division, General Motors Corporation Dayton, Ohio.

The new technical committee is an outgrowth of the symposium on powder metallurgy held in March 1943, and the great expansion in the use of powder-metal products.

National Electronics Conference To Meet in Chicago, Ill.

The first annual National Electronics Conference which is described as a "national forum for electronic developments and their engineering applications," will be held at the Medinah Club, Chicago, Ill., October 5–7, 1944.

Sponsored jointly by the Illinois Institute of Technology, Northwestern University, the Chicago section of the Institute of Radio Engineers, and the Chicago Section of the AIEE, the conference will provide a common meeting place for technical personnel interested in applications in the broad field of electronics. Particular attention is being given to the needs of the many industrial engineers who have used electronic methods in restricted and specialized applications. Technical papers and discussion groups are being planned to treat the communication, industrial, measurement, instrumentation, control, research, and medical applications of electronics. One session will be devoted to educational problems and an electronic curriculum for technical schools and colleges. A. B. Bronwell (A '34) assistant professor of electrical engineering, Northwestern University, Evanston, Ill., is chairman of the program committee and Beverly Dudley, 520 North Michigan Avenue, Chicago, Ill., is secretary.

Effect of Welding on Ductility Now Predetermined. A new system for predetermining the loss of ductility in the base metal adjacent to a weld is proposed in a recent publication of the American Welding Society, "Guide to Weldability of Steels." Once a design and a welding process for fabricating it have been decided upon the data necessary for determining the effect of welding procedure upon the ductility of the heated zone adjacent to the weld in plain carbon and low-alloy steels may be found in the guide. Apart from the data in the book only two tests are required—an end quench and a notch-bend of the steel. Part I of the guide explains the system, and part II is designed as an instruction manual in its use. The guide is intended to facilitate a prompt and thorough test of the proposed system by welding engineers. Development of the system was initiated by Lehigh University under the sponsorship of the Welding Research Council and later taken over by the National Defense Research Council. The Welding Research Council, 29 West 39th Street, New York 18, N. Y., is soliciting reports from industry on success or difficulty in the use of the system. Copies of the guide may be obtained for $1.

Future Meetings of Other Societies

American Society for Testing Materials. 47th annual meeting, June 26–30, 1944, New York, N. Y.

American Society of Civil Engineers. July 16–21, 1944, Chicago, Ill.

American Society of Mechanical Engineers. Semi-annual meeting, June 19–20, 1944, Pittsburgh, Pa.

Fall meeting, October 2–5, 1944, Cincinnati, Ohio.

Canadian Electrical Association. Annual meeting, June 22–23, 1944, Murray Bay, Que.

Society for the Promotion of Engineering Education. Annual meeting, June 22–25, 1944, Cincinnati, Ohio.

Purdue Installs Power-Network Analyzer

D. D. Ewing (F '21) professor and head of the Purdue University school of electrical engineering, demonstrates the university's new network analyzer to representatives of the Midwest power companies which co-operated in its purchase and installation. Capable of solving in a few days, problems which would require months by the analytical method, the analyzer can reconstruct in miniature the operations of any power system. The available circuit elements can represent simultaneously 16 generator stations, 160 transmission lines and transformers, and 40 loads, which are adequate for studies on even the largest power systems. By setting up the projected system on the board, engineers planning additions of lines or equipment can judge the efficacy of the new equipment in advance. Particularly valuable are the possibilities of short-circuit studies for determining protective relaying settings. Such studies on an actual system would entail unwarranted damage. The co-operating companies to which the board will be available are: The American Gas and Electric Service Corporation, Cincinnati Gas and Electric Company, Dayton Power and Light Company, Indianapolis Power and Light Company, Louisville Gas and Electric Company, Northern Indiana Public Service Company, and the Public Service Company of Indiana. Other companies may obtain operating time upon application to the university. J. B. Ward (A '40) instructor in the school of engineering will direct operation of the board.

NEMA Adopts Induction- and Dielectric-Heating Standards

Seven new standards for electronic equipment for induction and dielectric heating have been adopted by the electronics section of the National Electrical Manufacturers Association. They are listed as follows:

EL 5–5 Output Ratings
EL 5–10 Ratings of Tubes and Parts
EL 5–15 Radio Interference
EL 5–20 Protection of Personnel
EL 5–25 Protective Equipment
EL 50–5 Induction Heating—Definition
EL 50–10 Dielectric Heating—Definition

Copies of the standards may be obtained from NEMA headquarters 155 East 44th St., New York, N. Y.

JOINT ACTIVITIES

ASA Co-ordinates Symbols for Electrical Designs

A compilation of a consistent set of graphical symbols for electrical and electronic equipment, titled, "Co-ordination of Electrical Graphical Symbols," has been published as an American War Standard by the American Standards Association. In the War Standard all outright conflicts in usage have been eliminated. Alternate symbols

have been tolerated only where the use of a symbol is so deep-seated in an industry that change would cause undue hardship.

The problem of conflicting symbols had become acute particularly since the war when the divergent sets of symbols used by the power industry and the communications industry began to overlap because of the expansion of electronic devices in communication, control, and detecting devices. By compromise the new standard has obviated previous practice in which one symbol was sometimes used to indicate two different pieces of apparatus or two different symbols used for the same equipment. Representatives of technical societies, trade associations, the War and Navy Departments, the Aeronautical Board, the National Aircraft Standards Committee, and industrial organizations participated in developing the standard.

Copies of the new Standard Z32.11–1944 may be obtained for 10 cents a copy from the ASA, 29 West 39th Street, New York 18, N. Y.

Two Radio Standards Issued by ASA

In an effort to increase production of radio parts the American Standards Association has completed two new American War Standards, "Power-Type Wire-Wound Rheostats" (C75.9–1944) and "Variable Wire-Wound Resistors" (C75.10–1944). It is expected that the Standards will be used in the design of new equipment; in preparation of new manufacturing facilities; and for procurement purposes.

Keyed to the requirements of the Armed Forces, both standards include applicable specifications and drawings; classification; materials and workmanship; general and detailed requirements; methods of sampling; inspection and tests; and packaging, packing, and marking for shipment. A combined committee of representatives of the radio industry and the Armed Forces drew up the standards, and they already have been adopted by the United States Navy Department's Bureau of Ships and the Signal Corps Standards Agency of the United States Army.

The main difference between the two Standards is the greater power dissipated by the power-type wound rheostat because of a higher operating temperature. The variable wire-wound resistor with its low operating temperature is employed chiefly in radio and electronic devices.

The Standard on the power-type rheostat is 50 cents per copy and the Standard on the variable resistor is 40 cents per copy. They may be obtained from the American Standards Association, 29 West 39th Street, New York 18, N. Y. They are available without charge for procurement purposes only from the Government agencies concerned.

ASA Approves Two Standards on Electrical Insulating Materials

Two standards of the American Society for Testing Materials have been approved recently by the American Standards Association. These are the previously approved and recently revised American Standard Tentative Methods of Testing Molded Materials Used for Electrical Insulation (C59.1–1944) and the new American Standard Methods of Testing Sheet and Plate Materials Used in Electrical Insulation (C59.13–1943), developed by the ASTM committee on electrical insulating materials.

The first of these Standards applies to all solid electrical insulating materials (except dry-process porcelain) formed in molds by the application of pressure, either with or without heat, and includes only special instructions pertaining to the preparation and testing of these materials. Methods of test are described for acetone extraction, arc resistance, compressive strength, dielectric strength, deformation under load, distortion under heat, and similar conditions.

The second of these Standards covers the procedures for testing stiff, flat-sheet, and plate materials such as phenolic and other types of laminated sheets, hard rubber, asbestos, composition board, and others, to be used as electrical insulation, except as modified by the individual methods or specifications for a particular material. The standard includes definitions of terms used; directions for conditioning apparatus; and procedure for testing thickness, tensile strength, flexural strength, compressive strength, resistance to impact, water absorption, volatile matter, and the like.

Copies of the Standards are availabe and can be obtained from ASA, 29 West 39th St., New York, N. Y., at 25 cents per copy.

ECPD Issues Pamphlet on Joint Local Groups

A concise explanation of the plan recently devised by the Engineers' Council for Professional Development for the organization of joint local engineering groups to further the objectives of the Council on the level of the individual engineer is offered in a new eight-page pamphlet, "Will You Help?" Although the plan is directed primarily toward the local sections of the Council's eight participating societies other local engineering organizations and interested groups are invited to take part. It is hoped that the pamphlet, which is available upon request, will stimulate growth of more groups such as have been organized to work in the local field for the establishment of engineering on a sound professional foundation. The four standing committees of ECPD are prepared to extend general guidance to the local groups. The committees also will assist the local organizers by answering questions, by supplying information about the other local groups, and by making suggestions based on their observations. Inquiries may be addressed to the Engineers' Council for Professional Development, 29 West 39th Street, New York 18, N. Y.

EDUCATION • • •

Rutgers University Organizes Research Council

Creation of a research council to promote research in all departments of the university has been announced by Rutgers University, New Brunswick, N. J.

A special fund has been placed at the disposal of the council and a survey of personnel and facilities is being made to determine the best projects for investment of new funds. Emphasis will be placed upon co-operative research between departments and between outside organizations and university departments. Applications for grants for next year are being considered now.

William H. Cole, professor of physiology and biochemistry, has been appointed director of the new council, and James L. Potter (A '41) professor of electrical engineering, has been named one of its nine members. Doctor Cole will represent the university in developing reciprocal arrangements with governmental, industrial, business, and professional institutions.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Mercury Thermometers in 60-Cycle Fields

To the Editor:

There has been recurrent discussion concerning use of mercury thermometers in 60-cycle magnetic fields, because internal heating of the mercury by eddy currents tends to make the temperature indication higher than would be shown by a spirit thermometer in the same location. The amount of error is of interest because mercury instruments sometimes are preferable in other respects.

In testing a 2,666-kva 2,400-ampere reactor some years ago, mercury thermometers were observed to be registering several degrees higher than nearby spirit thermometers. Most of the difference may have been nonmagnetic in origin, however.

In a recent experiment by the writer, a difference of 0.6 degree centigrade was observed in a field of 40 kilolines per square inch. The setup comprised a water-cooled solenoid 4 inches in diameter and 4 inches long, with mercury and spirit thermometers corked into a small glass thermos flask, inside the winding. The mercury bulb was

$^{1}/_{32}$ inch in diameter by $^{3}/_{4}$ inch long. The test was run for 15 minutes, and the difference in readings became constant after ten minutes. Field strength was measured by a pickup coil wound on the outside of the flask; this coil also showed when the bulbs were centered in the maximum field. Since this field strength was much higher than would be encountered in almost any usual equipment, including reactors, it would appear that mercury thermometers of similar dimensions can be used freely in 60-cycle fields.

A moderate amount of searching has not brought to light any quantitative statements on this subject, and further information therefore would be much appreciated.

JEROME J. TAYLOR (A '40)

(Electrical engineer, Detroit (Mich.) Edison Company)

NEW BOOKS . . .

The following new books are among those recently received from the publishers. Books designated ESL are available at the Engineering Societies Library; these and thousands of other technical books may be borrowed from the library by mail by AIEE members. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books. All inquiries relating to the purchase of any book reviewed in these columns should be addressed to the publisher of the book in question.

Precision Measurement in the Metal Working Industry. Volume I, prepared by the Department of Education of International Business Machines Corporation. Syracuse University Press, Syracuse, N. Y., 1942. 263 pages, illustrated, 11 by 8 inches, cloth, $2.75. (ESL.)

This is a revised edition of the manual on precision measurement and inspection methods in metal working originally prepared for use in training International Business Machines Corporation workers. Volume I contains the first seven chapters dealing with measurement in general, nonprecision line-graduated instruments, micrometer and vernier types, precision gauge blocks, fixed gauges, thread gauges, dial gauges, and test indicators. Volume II, now in process, will treat the more advanced types.

Rubber Red Book. Directory of the Rubber Industry. 1943 edition, fourth issue. Published biennially by *The Rubber Age*, New York 19, N. Y. 579 pages, illustrated, $9^{1}/_{2}$ by 6 inches, cloth, $5. (ESL.)

This directory of the rubber industry lists the rubber manufacturers of the United States and Canada, the manufacturers of rubber machinery and accessories, and the suppliers of chemicals, fabrics, and crude rubber. The varieties of synthetic rubber and their makers are listed. Other listings include rubber reclaimers and scrap dealers, rubber derivatives and rubber latex, consultants, sales agents, technical journals, organizations, and a directory of men prominent in the industry.

Meteorology, Theoretical and Applied. By E. W. Hewson and R. W. Longley. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1944. $8^{1}/_{4}$ by $5^{1}/_{2}$ inches, cloth, $4.75. (ESL.)

The object of this book is to give a well-rounded view of the essentials of meteorology. Part I deals with theoretical meteorology: the physical and thermodynamical characteristics of air; the movements of air masses; and the statistical analysis of meteorological data. Part II covers applied meteorology: instruments and observational procedures; climatology; map analysis and precasting procedure; and the applications of meteorology to other specialized fields.

Occupational Index. Volume 8, numbers 1–5, January, April, July, October, and Index, 1943. References 1–375. Occupational Index, Inc., New York University, New York, N. Y. 10 by 7 inches, paper, $5, annual subscription. (ESL.)

This bibliography, issued quarterly, contains annotated references to current pamphlets, books, and magazine articles containing information about opportunities in various occupations. Over 300 publications are listed in 1943. The annotations are clear and informative. Indexes by author, title, and subject are provided. Both military and civilian occupations are covered.

Practical Design of Welded Steel Structures. By H. M. Priest. American Welding Society, 33 West 39th Street, New York 18, N. Y., 1943. 153 pages, illustrated, 8 by 5 inches, cloth, $1. (ESL.)

The essentials of welding and welded construction are presented in concise form as a working manual for the practical welder and designer. The various welding processes, forms of joints, and weld testing are discussed. The general and detail design considerations for simple welded joints and connections precede their application to typical structural members. A separate chapter is devoted to the problem of fatigue.

Strength of Materials. By H. F. Girvin. International Textbook Company, Scranton, Pa., 1944. 357 pages, illustrated, 9 by 6 inches, cloth, $3. (ESL.)

After a survey of the first courses in strength of materials given at our larger colleges, Professor Girvin prepared this textbook. It aims to give the student thorough training in basic principles and to avoid attention to specialized topics better treated in later courses in design. The area–moment method of determining deflections is emphasized. A large number of problems are included.

Materials Handbook. By G. S. Brady. Fifth edition. McGraw-Hill Book Company, Inc., New York, N. Y., and London, England, 1944. 765 pages, illustrated, 9 by $5^{3}/_{4}$ inches, cloth, $5. (ESL.)

This handbook provides a quick source of information on the characteristics of materials of industrial importance. It will be useful to purchasing agents, designers, executives, and others. The arrangement is alphabetical with a good index to trade names and synonyms. The new edition has been revised carefully and is larger than preceding ones.

Modern Drafting. By W. H. Johnson and L. V. Newkirk. The Macmillan Company, New York, N. Y., 1944. 197 pages, illustrated, 11 by 8 inches, cloth, $2.50. (ESL.)

This textbook, intended for use by students at the high-school level, attempts to provide a course in the fundamentals of drafting and its industrial applications, which will enable the student to go to work. Chapters are devoted to pictorial drawing; sheet-metal, machine, and aircraft drafting; architectural drafting; and graphs and maps.

Power and Flight. By A. Jordanoff. Harper and Brothers, New York, N. Y., and London, England, 1944. 314 pages, illustrated, 10 by 7 inches, cloth, $3.50. (ESL.)

A readable elementary text intended for students and mechanics on the aircraft power plant and its maintenance. It also will be useful to others who wish to know something about aircraft engines. The book is distinguished by over 400 illustrations which clarify the text.

PAMPHLETS . . .

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.

Valuations, Appraisals, Inventories. Ford, Bacon and Davis, Inc., 39 Broadway, New York, N. Y., 11 pages.

Hearings Before the Subcommittee on Military Affairs, United States Senate, on Problems of War Contracts and Their Relations to Small Business. Smaller War Plants Corporation, Washington, D. C., 27 pages.

War Production Issue, May Facts. George S. May Company, 2600 North Shore Avenue, Chicago, Ill., 8 pages.

Resistance Welding. R. T. Gillette, General Electric Company, Schenectady, N. Y., 28 pages.

Fourteenth Report to Congress on Lend-Lease Operations. Superintendent of Documents, United States Government Printing Office, Washington 25, D. C., 84 pages, 20 cents.

Scheduling Primer. War Production Board, Washington, D. C., 16 pages.

A Table of Common Hazardous Chemicals. National Fire Protection Association, 60 Batterymarch Street, Boston 10, Mass., 31 pages, 30 cents.

Radio Markets After the War. Institute of Radio Engineers, Inc., 330 West 42d Street, New York 18, N. Y., 26 pages, 50 cents.

Distribution of Safety Equipment by Major Consuming Industries—1943. War Production Board, Washington, D. C., unpaged.

American Standard Symbols for Electrical Diagrams. I-T-E Circuit Breaker Company, 19th and Hamilton Streets, Philadelphia 30, Pa., chart.

U L Symbol of Safety. Underwriters' Laboratories, Inc., 207 East Ohio Street, Chicago, Ill., 32 pages.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Present D-C Aircraft Electric-Supply Systems

H. C. ANDERSON
ASSOCIATE AIEE

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THE multigenerator aircraft d-c electric system represents an important type which has proved its practicability under military-combat conditions. Proper parallel operation is maintained during extreme conditions of unequal generator speeds and accelerations by using an old but heretofore little-used method, which was first suggested and demonstrated for this application by L. W. Thompson. The successful parallel operation, therefore—the reliability and flexibility of the electric-supply system—is made possible chiefly by the use of voltage regulators, which provide for load division as well as voltage constancy. It was natural that difficulties initially experienced in service were not always clearly understood, and that the equipment and installation in the early stages did not have characteristics which would allow the system to operate with its greatest capabilities.[1] However, with experience and study the causes of these difficulties were determined and remedial measures taken. These changes, although only minor individually, when put into effect collectively, made for a considerable improvement in system performance. The result has been a more reliable system requiring less attention from the crew—a factor of paramount importance for a military plane. This improved reliability in turn contributes to the assignment of more functions to the electric system.

The development and refinement of the system and its control are truly a product of World War II, realized and continually improved through the cooperative effort of Army, Navy, and manufacturers' engineers. It seems appropriate that some of the problems associated with this unique type of system be discussed at this time, so that its inherent characteristics will be better understood. This paper deals with the type of system at present used by the multiengine Army type of plane. However, results can also be interpreted for the Navy type of d-c system. The emphasis of the paper is primarily upon the performance of the present system and not on developments now in progress, some of which have been or are being discussed in other papers. This paper is devoted to details of performance, the significance of which has been enhanced, not only by present military use, but by the possible adoption of a similar system for commercial aviation in the postwar period and for d-c systems more generally.

A schematic diagram of the type of aircraft electric system discussed in this paper is shown in Figure 1. An aircraft generator is connected directly to each of the four engines on the airplane. Proper parallel operation is obtained by applying a drop of 0.5 volt at full load in each of the generator negative leads to a circuit consisting of equalizer windings in the regulators. A remote-control relay which opens on the flow of reverse current provides generator switching control.

A brief summary of six of the important system problems investigated includes load division, system-voltage accuracy, reverse-current relay-contactor chatter, heavy transient loads, generator-output capacity, and short-circuit currents. Following this summary each of these problems is discussed more completely.

Load Division

Load division has been found to be affected by two major factors. These are circuit installation and regulator accuracy.

The first, which is primarily the airplane manufacturer's responsibility, requires

(*a*). That the total negative lead resistance, between the points where the equalizer-coil connections are made, be equal between generators.

(*b*). That there be no appreciable contact drop (nonlinear resistance) between points in the negative leads where the equalizer connections are made.

(*c*). That the resistance of the common lead for the field circuit and regulator coil of the regulator be small.

Voltage-regulator accuracy, that is, ability to hold voltage under all load, engine-speed, temperature, and vibration conditions, is important for proper load division. The attention given this problem by the regulator manufacturers is resulting in continued improvements in regulator accuracy.

System-Voltage Accuracy

The necessity for accurate bus voltage is determined chiefly by the battery characteristics which allow for some variation. The load voltage is determined by the voltage regulators.[2,3] It has been the practice for Army multiengine planes using up to four generators to have the equalizer coil of a disconnected generator left connected, resulting in a reduction in bus voltage. This reduction depends upon the number of generators disconnected compared to those left connected. The reduction in voltage can be avoided by providing manual means to disconnect the equalizer coils of the disconnected generators.

Another factor which has produced large variations in bus voltage has been the continued attempts of the operators to balance the loads by adjustment of the voltage regulators when improper plane circuit installation inherently would not

Paper 44-32, recommended by the AIEE committee on air transportation for presentation at the AIEE winter technical meeting, New York, N. Y., January 24-28, 1944. Manuscript submitted November 5, 1943; made available for printing December 3, 1943.

H. C. ANDERSON, S. B. CRARY, and N. R. SCHULTZ are in the analytical division, central station engineering, General Electric Company, Schenectady, N. Y.

The writers acknowledge the co-operation and helpful suggestions of the following engineers of the General Electric Company: L. W. Thompson and F. E. Crever of the voltage-regulator-engineering division, F. B. Hornby and F. M. Potter of the motor-engineering division, and A. A. Emmerling of the general-engineering laboratory. The constructive criticism and suggestions by H. J. Finison and Lieutenant Lusk of the Matériel Command, Wright Field, Dayton, Ohio, were greatly appreciated.

allow for accurate load division for all conditions with one setting of the regulators.

Transients due to starting turrets, landing-gear motors, and so forth are appreciable and may result in instantaneous voltage dips of 30 per cent or more. Equipment essential to flight and combat should be made as insensitive to such voltage variations as is practicable.

Relay-Contactor Chatter

Relay-contactor chatter results from

(*a*). Parallel operation at light load.

(*b*). Generators with a rising-regulation characteristic (overcompounded).

(*c*). Relay contactors having reverse-current drop-out settings which are too low.

Contactor chatter with light system load probably cannot be entirely avoided.

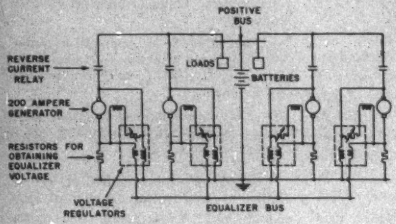


Figure 1. Schematic diagram of typical four-generator aircraft electric-supply system

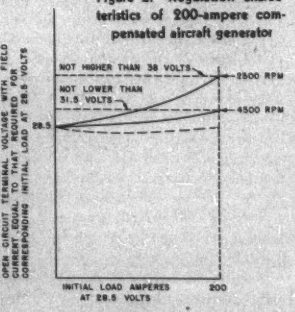

NOT HIGHER THAN 38 VOLTS
2500 RPM
NOT LOWER THAN 31.5 VOLTS
4500 RPM
28.5
OPEN-CIRCUIT TERMINAL VOLTAGE WITH FIELD CURRENT EQUAL TO THAT REQUIRED FOR CORRESPONDING INITIAL LOAD AT 28.5 VOLTS
INITIAL LOAD AMPERES AT 28.5 VOLTS
200

Figure 2. Regulation characteristics of 200-ampere compensated aircraft generator

However, with improvements in the factors which affect load division, the relay contactor chatter at light load has been reduced materially.

A severe type of contactor chatter can be obtained from a generator which has a rising-load-regulation characteristic. Such a regulation characteristic will also tend to produce instability of voltage regulation during parallel operation. Manufacturers, in their design of aircraft generators, have been careful not to obtain a rising-voltage-regulation characteristic for any part of the speed and load range over which the generator must operate. This becomes a prime design factor and must be given proper attention both in design and production testing in order that the generators will not have such a characteristic. If the generator brushes are rotated against rotation, a generator although properly designed in this respect may have a rising characteristic such as to cause severe contactor chatter. Therefore, it is important for this reason also that the generator brushes be properly set and fixed.

Reverse-current drop-out settings of the contactors had been initially specified to be from 0 to 10 amperes with a pickup voltage of 26 to 27 volts. This inherently resulted in chatter under light-system-load conditions. The reverse-current drop-out band was increased to a band of 8 to 20 amperes reverse current with 27.5 volts on the pickup coil.

With steps made to improve circuit installation, voltage-regulator accuracy, relay-contactor accuracy, generator characteristics, and, to increase relay drop-out settings, relay chatter was greatly reduced as a serious problem.

Heavy Transient Loads

The turret motor Amplidyne or generator sets require some of the largest inrush currents of any equipment on the airplane. It is important, therefore, that the electric supply system have sufficient electrical stiffness to support the bus voltage when the turret motor sets are started. The stiffness of the electric system is increased by the number of batteries, number of generators, and high generator speeds at the time the turrets are started, while the required amount of electrical stiffness is determined by the amount of starting current required. It was found that the number of batteries greatly affected the amount of starting current that could be made available. This is particularly true if it is necessary to start the turrets with some of the available generators disconnected. Accordingly, it appears that the batteries have a very important function in helping to support the bus voltage for the shock loads incident to turret starting.

Generator-Output Capacity

Two major factors affect generator-output capacity:

1. Generator design.
2. Regulator design and circuit installation.

The first is determined among other design factors primarily by whether the generator is compensated or uncompensated. The second factor is determined primarily by field-circuit resistance, which includes field leads in the airplane and the regulator minimum resistance. The output capacity of a generator may be reduced very materially by generators of uncompensated design having appreciable field-circuit resistance caused by long field leads and the use of regulators having high minimum resistance. On the other hand, the load-output capacity of a generator may be very materially improved by using generators of compensated design and regulators having low minimum-field resistance. The compensated generator was first proposed and demonstrated for this application by S. R. Bergman.[4]

Short-Circuit Currents

The modern four-engine airplane with three batteries is capable of producing total instantaneous short-circuit currents approaching 5,000 amperes. It appears, therefore, that the reverse-current contactors, which were originally specified for interruption of currents of 500 amperes and more recently improved for rated interruption of current up to 2,400 amperes, are not entirely adequate for short-circuit protection. Additional pro-

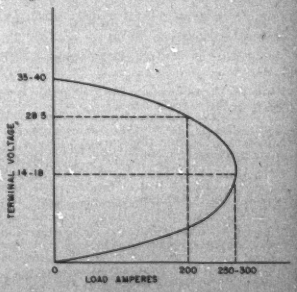


Figure 3. Volt-ampere characteristic of 200-ampere compensated aircraft generator operating without voltage regulator at 2,500 rpm

tection is desirable, since complete reliance cannot be placed on all faults to burn themselves clear[5] without appreciable damage. Accordingly, consideration is being given to proper circuit-breaker protection and contactors of higher interrupting rating.[6] Reverse-current circuit breakers provide an effective method of protecting the vital generation and battery supply currents.

Conclusions

Considerable improvement in the operation and performance of the present type of electric-supply systems for aircraft has been and can be further realized by

1. Improvements in the circuit installation.
2. Continued refinements in the generator, regulator, and reverse-current relay-contactor characteristics.
3. The use of compensated generators, regulators with low minimum resistance, and circuit installation using low-resistance field leads.
4. The use of directional protective breakers or switches in the battery and generator circuits.

Aircraft D-C Generator Characteristics

(a). Generator-Regulation Characteristics

Since the generator-regulation characteristic depends to a great extent on brush setting, it is important that brushes be set correctly in order to avoid a rising characteristic which may result in instability in parallel operation and severe contactor chatter (also possible instability when connected to a battery). Rotation of the brushes in a direction opposite to machine rotation tends to produce a rising characteristic.

Figure 2 illustrates a typical regulation characteristic as determined by laboratory tests on a compensated 200-ampere aircraft generator, at 2,500 and 4,500 rpm. The ordinate is the open-circuit terminal voltage obtained with field current required for the load indicated on the abscissas at 28.5 volts. This voltage, therefore, corresponds to the machine internal voltage for the given load condition. If the curves are as shown by the full lines of Figure 2, the generator is said to have a drooping characteristic at all loads, that is, the terminal voltage drops with increase in load at constant field current. If a generator has a characteristic as shown by the dotted line, it has a rising characteristic at light load; that is, the terminal voltage rises with increase in load at constant field current. Such a generator may cause severe contactor chatter, resulting in failure of the contactor, and also cause instability in parallel operation during light loads.

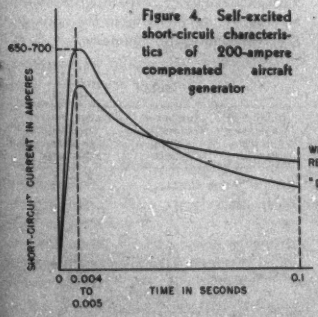


Figure 4. Self-excited short-circuit characteristics of 200-ampere compensated aircraft generator

(b). Self-Excited Generator Volt-Ampere Characteristic

Figure 3 illustrates the general shape of the volt-ampere characteristic for a self-excited d-c generator operating without a voltage regulator. The field resistance is held constant at a value which gives approximately rated current at rated terminal voltage. The maximum current available depends on generator speed, excitation, brush setting, temperature, and commutation limitations.

At a generator speed of 4,500 rpm, it has been found that the volt-ampere characteristic has about the same shape and proportions as that for 2,500 rpm, when the field rheostat is set for rated load at rated terminal voltage. When a voltage regulator is used, however, the maximum current at high speed exceeds that at low speeds because of the lower excitation requirements at higher speeds.

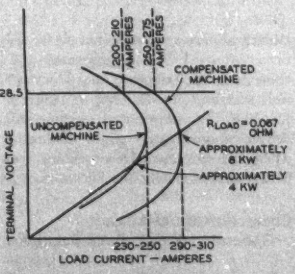


Figure 5. Comparison of volt-ampere characteristics for compensated and uncompensated aircraft generators operating at 2,500 rpm with $r_f/_a = 0.25$ ohm

r_f = field-circuit resistance external to field

(c). Self-Excited Short-Circuit Characteristic

Because of the relatively fast time constant of the armature circuit, the generator short-circuit current rises rapidly to its maximum value and decays to a sustained value at a rate determined principally by the time constant of the generator field circuit.

For a given generator speed and excitation, the maximum initial value of short-circuit current occurs for a dead short circuit at the generator terminals. This, however, does not give rise to the maximum value of sustained current. The fault resistance which will result in the largest value of sustained current may be determined from the generator volt-ampere characteristic.

A typical 200-ampere generator short-circuit characteristic as obtained with an oscillograph is shown in Figure 4. Specific values indicated on the curve are characteristic of a compensated 200-ampere aircraft generator operating at full load previous to the short circuit. If the generator is assumed to supply full load at rated voltage before the application of the fault, the initial value of the short-circuit current is practically independent of the generator speed.

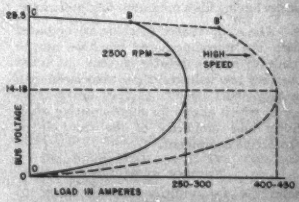


Figure 6. Volt-ampere characteristic of 200-ampere compensated aircraft generator operating with voltage regulator

The sustained value of short-circuit current depends on the fault resistance, the generator speed, and the operation of the voltage regulator. The sustained current may be increased appreciably by operation of the voltage regulator; in fact, for relatively high values of fault resistance and generator speeds, it is possible for the sustained short-circuit current to exceed the initial value.

(d). Compensation and its Effects on Generator Performance

D-c aircraft generators must have a drooping load-regulation characteristic to

allow for stable operation under voltage-regulator control and to minimize relay-contactor chatter. On the other hand, a generator with a large droop will not be capable of as great an output under heavy-overload conditions. One of the most efficient ways of controlling the amount of droop is by the use of compensating windings. This has several very desirable effects.

1. Under emergency-overload conditions, the generator is capable of sustaining a much greater load than would be the case if it were uncompensated. This is of value under sudden-transient-load conditions, particularly when some of the generator capacity (on a multigenerator system) is disconnected. Also the use of compensated generators allows for the starting of higher starting-current loads and results in higher starting torque and greater acceleration of the load. This may be evaluated also in terms of obtaining better performance under emergency conditions with a reduced number of generators or batteries. Both of these are important from the standpoint of weight and reliability of operation.

2. The compensated machine allows for better commutation at higher loads and under short-circuit conditions. The proper short-circuit protection of an airplane makes it desirable that, with the occurrence of a system short circuit, none of the generators' commutators flash over.

3. A compensated machine, because of its reduced requirement for change in field current under overload conditions, is not affected so adversely as the uncompensated machine for high field-circuit resistance associated with long field leads or with regulators having high minimum-field resistance.

4. The compensated machine as compared with the uncompensated machine can be made to have a greater current output at the very low voltages, those associated with system short circuit, or very heavy overloads, which allows for more positive selectivity and simplicity of the short-circuit protective equipment.

It is a primary system-design characteristic for multiengine airplanes to provide an amount of generator compensation in order to obtain the maximum output of the generators under all system-operating conditions and at the same time to allow for proper stable parallel operation under regulator control. Both generators and regulators can be so designed to meet the optimum-system-performance characteristics desired.

The general shapes of the volt-ampere characteristics for compensated and uncompensated machines of the same rating are shown in Figure 5. It will be noted that the difference in peak current for the uncompensated and compensated machines is about 60 amperes. For a constant resistance load of 0.067 ohm, as shown in Figure 5, the compensated machine will deliver approximately eight kilowatts, while the uncompensated machine will deliver approximately four kilowatts.

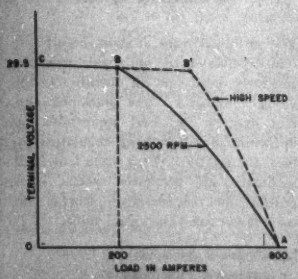


Figure 7. Volt-ampere characteristic of 200-ampere compensated aircraft generator operating with voltage regulator and battery

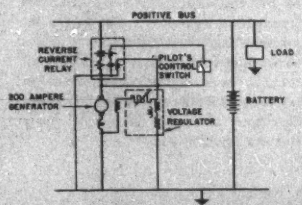
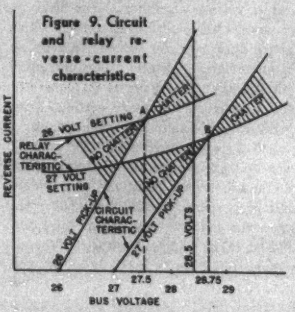


Figure 8. Connections of single-generator aircraft electric-supply system



Characteristics of Aircraft Generator With Voltage Regulator

Because of the wide ranges in speed and load to which an aircraft generator must be subjected and the different types and ratings of generators which may be used, a voltage regulator with a relatively large range of resistance must be employed.

The field resistance of the generator is varied by a direct-acting voltage regulator,[3,4] which controls only after the terminal voltage has reached the lower limit of the regulator setting, about 28 volts. The regulator has a magnetic circuit energized by a winding through a diluting resistor from the voltage of the generator being regulated. The force set up by the magnetic circuit is balanced against an adjustable calibrating spring. A second winding on the regulator is used to accomplish load equalization during the parallel operation of two or more generators.

When the generator is operated with a voltage regulator, the volt-ampere characteristic is similar to that shown in Figure 6. Curve *CBO* is for the base speed of the generator, 2,500 rpm. Curve *CB'O* is for a higher generator speed.

The portions of the curves *CB* and *CB'* may have a slight droop caused by resistance drop between the bus and the point at which the voltage is being regulated. At points *B* and *B'*, the voltage regulator becomes essentially inoperative, having reduced its variable resistance to a minimum value. When a compression type of regulator is used, the minimum value of regulator resistance is not absolutely constant but is a function of the generator terminal voltage. The parts of the curves *BO* and *B'O*, then, correspond to minimum field resistance. The value of load at which the regulator becomes inoperative increases with increasing generator speed because of the reduced excitation requirements.

Characteristics of a System Consisting of One Generator With Voltage Regulator, Reverse-Current Relay, and One Battery

(a). Volt-Ampere Characteristics

When a 24-volt battery is added to the system, the volt-ampere characteristic is similar to that shown in Figure 7. At a value of load corresponding to point *B* or *B'*, depending on the speed, the voltage regulators become essentially inoperative, having reduced the variable field resistances to minimum values.

Table I

Number of Generators in the System	Number of Generators Out of Service	System Voltage Drop Due to Dead Equalizers
2	1	2.2
4	1	1.1
	2	2.2
	3	3.3
6	1	0.73
	2	1.46
	3	2.2
	4	2.93
	5	3.67

Point *A* represents the battery short-circuit current, in this case 800 amperes.

The battery tends to produce a "stiffer" system than would be obtained with a generator alone; this factor is especially important in supplying heavy shock loads such as motor starting. Since the ampere-hour rating of aircraft batteries is quite small, however, it is not intended that they be called upon to supply heavy continuous loads.

(*b*). Reverse-Current-Relay Characteristics

Generator switching control is obtained by means of an automatic relay which is set to close at a predetermined generator voltage and will open upon the flow of current from the battery to the generator.[1,3] The reverse-current relay consists of a pilot relay and contactor mounted on the same base. The calibration for pickup voltage is made by adjusting the spring tension on the pilot relay. A heavy coil mounted on the pilot relay carries the generator current and opens the relay when the flow of current reaches a preset value in a reverse direction. When the pilot relay closes, the main contactor coil is energized, and the contactor closes, connecting the generator to the bus. Figure 8 shows the connections of the generator regulator and relay and their associated circuits.

Normally the relay is set to close between 26 and 27 volts. As the generator comes up to speed with the pilot's control switch closed, the terminal voltage reaches a value equal to the pickup voltage of the relay, and the relay closes. The bus voltage, if other generators are on the bus, is normally 28.5 volts, which will cause a current to flow in a reverse direction through the relay. Hence, there is a possibility of obtaining enough reverse current to open the relay, after which it will again close because of the voltage impressed upon it. These operations continue, and the relay chatters. This condition may cause a substantial shortening of the relay life. Figure 9 shows how this condition is materially improved by raising the reverse-current drop-out value or the pickup voltage.

In Figure 9, the curves marked "relay characteristic" indicate the amount of reverse current necessary to open the relay at a given bus voltage (or relay-coil voltage) for two relay pickup adjustments. The "circuit-characteristic" curves show the amount of reverse current which the circuit will deliver at a given bus voltage when the relay pickup voltage is less than the bus voltage.

For the particular relay characteristics shown in Figure 9, the relay will not chatter when set to pick up at 26 volts so long as the bus voltage before closing is less than 27.5 volts. If the relay is set to pick up at 27 volts, it will not chatter so long as the bus voltage before closing is less than 28.75 volts.

In normal operation there is a possibility that a relay set at 26 volts will be made to close on a bus of 28.5 volts. If the relay had characteristics as shown in Figure 9, it would chatter badly if the pickup voltage were set below 27 volts. However, if the point *A* were made to be to the right of the ordinate erected at 28.5 volts, the relay would not chatter. With higher reverse-current drop-out values the intersection *A* can be moved farther to the right, and the probability for relay chatter of the type discussed can be considerably reduced. The foregoing analysis applies for conditions of very light loads. If the system is supplying some load, the probability of this type of chatter is greatly reduced, since the equalizer winding in the regulator of the incoming generator will become effective in loading the generator.

If a generator has a rising voltage characteristic (series cumulative field effect) the circuit reverse-current characteristic will be steeper, and the relay will have a greater tendency to chatter, because it takes much less voltage difference between the terminal voltage and the open-circuit bus voltage to produce a large amount of reverse current. (The intersection *A* on Figure 9 would be farther to the left of the 28.5-volt ordinate.) Relay chatter due to this cause, therefore, cannot be avoided unless the incremental generator regulation is drooping.

Another cause of relay chatter is parallel operation with very light loads on the system, aggravated by voltage-regulator inaccuracies and unequal paralleling resistors in the negative leads of the generators. Under these conditions different voltage-regulator adjustments are required to balance the generator currents at each loading. Accordingly, if the regulators are adjusted for load balance at an appreciable system load, they will be unbalanced at other loads. At light load this unbalance may result in sufficient reverse current in some generators to cause relay chatter. Proper operation requires that the paralleling resistors in the generator negative leads be equal.

(*c*). Effect of Field-Circuit Resistance

As would be expected, the maximum output of a self-excited d-c generator for aircraft is determined to a considerable extent by the field-circuit resistance external to the field itself. Figure 10 shows the effect of resistance external to the fields of a compensated 200-ampere generator and an uncompensated 200-ampere generator. Values given in this figure are indicative of orders of magnitude. These characteristics show the reduction in maximum output caused by r_{fe}, the field-circuit resistance external to the field winding. It is important, therefore, in evaluating regulator performance, to determine the minimum resistance of which the regulator may be capable when operating with a given generator.

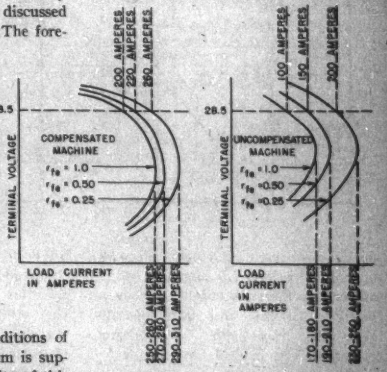


Figure 10. Effect of field-circuit resistance on compensated and uncompensated 200-ampere aircraft generators operating at 2,500 rpm

r_{fe} = field-circuit resistance external to field winding

Not only is the output of the generator reduced for higher values of field-circuit resistance, but with a 0.75-ohm increase in the field-circuit resistance, the minimum generator speed at which the regulator begins to control is increased by about 120 rpm when the regulator is set for 28.5 volts. Increasing the minimum-field resistance by 0.75 ohm increases the generator speed at which the reverse-current relay picks up by about 150 rpm with a 26-volt pickup setting of the relay. These values are representative of a system using generators having 2 to 3 ohms field resistance.

(*d*). Generator Cooling

Insufficient cooling of generators will have a pronounced effect on their maximum output, from the standpoint of increased field resistance, as well as from the standpoint of increased armature resistance. When the generators are operating at full load at a low to medium speed, the regulators are inserting very little resistance into the field circuit. The field-circuit resistance is then largely the resistance of the field itself. In reference to Figure 10, it can be seen that an increase of 0.1 ohm in the field-circuit resistance causes decreases of approximately 7.5 amperes and 14 amperes in the peak outputs of compensated generators and uncompensated generators, respectively. A ten-degree-centigrade rise in field temperature will produce approximately a 0.1-ohm increase in field resistance. From the foregoing, it can be said that from the standpoint of increase in field-circuit resistance alone, the effect of temperature rise on an uncompensated machine is approximately twice that on a compensated machine. At heavy loads each ten-degree-centigrade rise in temperature will decrease the maximum output of an uncompensated machine approximately 14 amperes. For the compensated machine the decrease will be only 7.5 amperes.

Multigenerator Systems

(*a*). Description

Four generators are operated in parallel as shown in Figure 11. Each regulator is provided with an equalizer winding which is wound in a direction such as to compensate for the unbalanced load between generators. Equalizer potential is obtained by using the drop in resistors of equal value in the negative leads of the generators. Regulators are usually installed in the fuselage of the airplane where they can be readily adjusted. Relays are generally installed close to the engine-driven generators in the nacelles. Batteries connected to the main d-c bus are located in the fuselage.

(*b*). Parallel Operation and Load Division

1. Unbalances Due to Circuit Installation. In reference to Figure 11, an elementary sketch of a four-engine airplane electrical system assumed to be symmetrical about the load, R_1 and R_2 are positive-lead resistances; R_3 and R_4 are negative-circuit resistances set up by the bonding of the negative leads to the structure of the airplane and the structure of the airplane itself; R_5 and R_7 are equalizer-lead resistances; r_s is the resistance of the equalizer coil; r_s is the resistance of the equalizer shunts; I_1, I_2, I_3, and I_4 are the currents supplied by the generators; and I is the total load current.

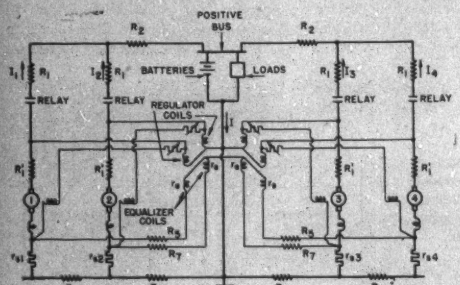


Figure 11. Connections of four-generator aircraft electric-supply system

If it is assumed that the identical voltage regulators have equal no-load settings, analysis of the aforementioned system indicates that load division is affected primarily by the shunt and ground resistances, r_s and R_3 respectively. If the various shunt resistances are equal, that is, if $r_{s1}=r_{s2}=r_{s3}=r_{s4}=r_s$, and if the voltage-regulator no-load settings are equal, the load division may be written approximately in terms of the following equations:

$$I_1=I_4 \tag{1}$$

$$I_2=I_3 \tag{2}$$

$$\frac{I_1}{I}\cong\frac{1}{2\left(2+\frac{R_3}{r_s}\right)}\cong\frac{I_4}{I} \tag{3}$$

From equation 3, it may be seen that if R_3 and r_s are equal, machines 1 and 4 will each supply only one sixth of the total current instead of one fourth of the total which is desired. (Machines 2 and 3 will each supply one third of the total current.) It is apparent that a decrease in the grounding resistance R_3 is necessary to improve load division. It has been found that the unbalance in the negative leads, R_3, is due to two things:

1. The resistance of the grounding structure itself (bolts, lugs, brackets, and so forth).
2. The fact that the lead resistances have not been equalized.

The airplane structure itself offers negligible resistance to the flow of current. If care is taken to make the negative leads of equal resistance and to ground the leads to a heavy portion of the airplane structure, R_3 becomes negligible ($R_3\cong 0$) and the balance under load is materially improved. If perfect load division were required, it would be necessary to balance the positive-lead resistances, R_1, the equalizer-lead resistances, and the regulator leads from the generator to the regulator coil. However, the effect on load division of unbalanced resistances in these leads is of second order. Their resistances, particularly those of the field leads, should be kept as low as possible in order to obtain maximum possible output from the generators.

2. Unbalances Due to Voltage Regulators. In addition to unbalance in load division due to the airplane circuits, considerable load unbalance can result from differences in voltage-regulator settings as small as ± 0.5 volt. For example, it is obvious that an undesirable current unbalance would exist if the regulators on the *outboard* generators were set at 28 volts, while the *inboard* regulators were set at 29 volts. This difference in voltage-regulator settings may result in load unbalances as high as ± 20 amperes (in systems employing an equalizer shunt voltage drop of 0.5 volt at 200 amperes) independent of unbalances due to unbalanced circuit resistances.

Variations from one regulator to another, as regards the ability of the regulator to hold voltage under all conditions of load, generator speed, and temperature will introduce additional unbalance in load division.

3. Effect of Removing Generators From Service While the Corresponding Equalizer Coils Remain Connected. It has been found by calculation and from test data that the effect of a "dead"* equalizer coil, or coils, upon *load division* is of secondary importance.

Dead equalizer coils, however, tend to reduce the system voltage. Both tests

* An equalizer coil which remains connected to the system after its generator has been removed from service.

and calculations indicate that, with the present voltage regulator using an equalizer shunt voltage drop of 0.5 volt at full load, the drop in system voltage, assuming that all equalizer coils remain connected and that the generators remaining in service are fully loaded is shown in Table I.

For systems which make use of a greater equalizer shunt voltage drop, the drop in system voltage due to dead equalizer coils will exceed the values indicated in Table I.

(c). Volt-Ampere Characteristic

A typical curve of bus-voltage versus load current for a four-generator system is as shown in Figure 12. This system in-

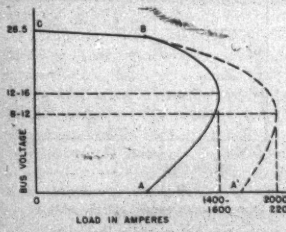


Figure 12. Volt-ampere characteristic of four-generator aircraft electric-supply system

Generators operating at 2,500 rpm

cludes voltage regulators and a battery. The portion of the curve *CB* has a slight droop with increasing load because of resistance between the bus and the points at which voltage is being regulated.

At point *B* the voltage regulators have reduced their variable resistance elements to the minimum ohmic values and are, therefore, essentially inoperative for the portion of the curve *BA*. Point *A* represents the value of short-circuit current contributed by the battery.

The effect of the battery, or batteries, is to produce a "stiffer" system, that is, to increase the maximum number of amperes available. This factor becomes important in the case of shock loads such as turret starting, and so forth. Shock loads should not be of such a resistance as to result in a collapse of system voltage. Curve *A'BC* is similar to curve *ABC*, except that the system includes three batteries rather than one. A comparison of the two curves illustrates the additional "stiffness" obtained by adding batteries to the electric system.

Table II

Number of 200-Ampere Generators	Number of 24-Volt Batteries	Approximate Maximum Sustained Fault Current in Amperes
4	3	3,400
3	3	3,000
2	3	2,500
4	2	2,800
4	1	2,400

For higher generator speeds, the maximum current available will exceed the values indicated in Figure 12 and will occur at somewhat lower voltages. The upper limits on maximum currents at high generator speeds will be governed by commutation, compensation, and saturation characteristics of the generators. It is quite possible that, with three batteries and generator speeds of 4,000 rpm, currents as high as 4,000 amperes may be obtained.

(d). Transient Loading

One of the most severe transients experienced on the electric system of military airplanes is caused by the starting of a turret motor Amplidyne or motor generator set. Figure 13 shows the variation in d-c bus voltage when a motor Amplidyne set is started on a four-engined airplane equipped with carbon-pile generator-voltage regulators. These transients were replotted from oscillograms taken during test flights.

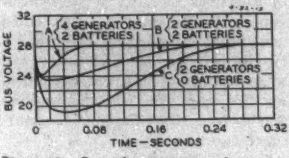


Figure 13. Bus voltage transient when motor Amplidyne set is started on an aircraft electric system

Generators operating at 3,000 rpm

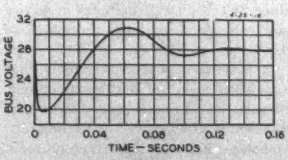


Figure 14. Bus voltage transient when landing gear is raised on four-generator aircraft electric system

Generators operating at 3,000 rpm. Three batteries on bus

The effect of the removal of generators and batteries from the supply system is clearly shown on the curves. A convenient basis upon which to compare different recovery characteristics for a constant loading condition is the area under the curves in volt-seconds. On this basis a relatively small area would correspond to a quick recovery and a small initial disturbance. For Figure 13 the following comparisons may be made:

Case	System Conditions	Volt-Seconds
A	4 generators, 2 batteries	0.12
B	2 generators, 2 batteries	0.52
C	2 generators, 0 batteries	1.21

Figure 13 and the preceding tabulation show clearly the effect of the loss of generators and batteries on the system transient characteristics.

Another severe transient load is that of the retraction of electrically operated landing gear. Figure 14 shows the variation in bus voltage when the landing gear of a four-engined plane is retracted. Actually the gear requires 20 to 30 seconds to retract fully. Figure 14 shows the initial transient, which is followed by a comparatively steady-state load of about 300 amperes of 20 to 30 seconds duration.

A 500-ampere resistance load suddenly applied to the system will cause a bus-voltage variation similar to that shown in Figure 15. Figures 14 and 15 are replots of oscillograms taken during actual flight tests on an airplane with four generators and three batteries supplying the electrical power.

(e). Short-Circuit Currents

Both test and analytic studies of a typical multigenerator electric-power-supply system indicate, as shown in Table II, approximate values of maximum sustained* short-circuit current as a function of system generating capacity (assuming that there is no motor load on the system):

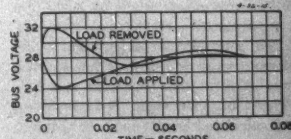


Figure 15. Bus voltage transient when 500-ampere resistance load is suddenly applied to a four-generator aircraft electric system

Generators operating at 3,000 rpm

With four 200-ampere generators and three 24-volt batteries in service, the approximate maximum value of reverse current (sustained) through any re-

* "Sustained" short-circuit current is herein defined as that short-circuit current which can be maintained for a few seconds rather than a period of minutes.

verse-current relay is 3,000 amperes. This condition can occur when the short circuit is located between a generator and its corresponding reverse-current relay.

In general, the magnitude of short circuit is dependent chiefly on the fault resistance and the number of generators and batteries in service. That is, for a given value of fault resistance and for a given number of generators and batteries in service, the short-circuit current has about the same value for a fault at any point in the supply system. The magnitude of short-circuit current also depends to some extent upon the speed of the generators. Table II was calculated on the basis of a generator speed of 3,200 rpm, assuming characteristics similar to those of a generator rated 5.7 kw, 28.5 volts, 200 amperes, 2,500/4,500 rpm, with commutating and compensating windings. Test results on this type of generator indicate that the short-time volt-ampere characteristic at 3,200 rpm is representative of the maximum sustained short-circuit current which the generators can deliver for a few seconds, even though the generator speed is higher than 3,200 rpm. Since both test and calculated results indicate that uncompensated generators produce appreciably less current at the low voltages encountered during short circuits, it is expected that the numerical results presented in Table II represent the maximum values of short-circuit current which may be expected.

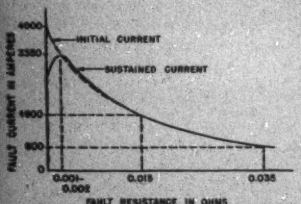


Figure 16. Fault currents on a four-generator aircraft electric system as a function of fault resistance

Three batteries in service

For a fault on a wing junction box, the fault current as a function of fault resistance is shown in Figure 16. For faults at the various generators and nacelle junction boxes, the results are much the same as shown in Figure 16.

Test and calculated data indicate that only for extremely small values of fault resistance does the initial short-circuit current exceed the sustained value. This is shown in Figure 16. At low generator speeds, however, the initial value is more likely to exceed the sustained value than at high generator speeds. The initial short-circuit current decreases with fault resistance, as shown in Figure 16, and becomes practically equal to the sustained value for fault resistances in excess of 0.001 to 0.002 ohm. The initial value is also a function of system loading prior to the fault, increasing somewhat as the system load previous to the fault is increased. In general, it is expected that the fault resistances actually encountered in practice will be of the order of magnitude to result in short-circuit currents having about the same initial and sustained values. Oscillographic records obtained on a laboratory test setup tend to confirm this conclusion. For this reason, the preceding explanation has been confined to sustained short-circuit currents.

Figure 17 illustrates the typical short-circuit-current characteristics as obtained by means of an oscillograph. The values indicated on the figure were obtained with four 200-ampere generators and three 24-volt aircraft batteries in service and correspond to fault resistances of 0.006 ohm and 0.001 ohm.

It may be seen from Figure 17 that even when the initial short-circuit current exceeds the sustained value, the initial transient is very short. It is thus improbable that the operation of most protective devices would occur before the sustained value of current was attained.

(f). Reverse-Current Protection of Generator and Battery Circuits

The short-circuit currents for faults in the generator and battery circuits may vary over a large range of values depending on the fault resistance and operating conditions prior to the fault. Also, for a given fault, the short-circuit currents contributed by the various generators are nearly equal. The difficulty, then, in obtaining adequate short-circuit protection with devices utilizing current *magnitude* only is obvious.

It is apparent, however, that for a given fault in the generator or battery circuits, the *direction* of current flow in the faulted circuit element is opposite to the normal direction of flow. Thus reverse current may be used to trip a reverse-current circuit breaker or switch to clear the fault.

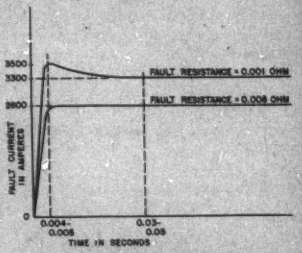


Figure 17. Short-circuit characteristic of a four-generator aircraft electric system

Three batteries in service

It is believed that a reverse-current circuit breaker is fundamental to the reliable protection of generator and battery circuits.

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Heating of Nonmagnetic Electric Conductors by Magnetic Induction—Longitudinal Flux

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HEAT can be generated in a piece of metal or other conducting material by wrapping a coil around the piece, such as the cylinder shown in Figure 1a, and causing a current of suitable magnitude and frequency to flow into the coil. This is called "induction heating." The great advantage of this type of heating is that the heating can be accomplished without contacting the piece to be heated. This allows the heating to take place while the piece is moving or enclosed in a protective atmosphere. Also, the heat usually can be concentrated just where it is needed, and a piece usually can be heated faster by induction than by any other method. The desirable frequency to use for induction heating depends on the size and the electrical properties of the piece to be heated and may vary from 25 or 60 cycles per second for heating joints in iron pipes to a few million cycles per second for heating very small nonmagnetic pieces for soldering. Frequencies up to 10,000 cycles per second are obtained usually from rotating machines; for higher frequencies one must resort to spark or vacuum-tube oscillators.

Induction heating finds a multitude of uses in industrial processes, such as surface hardening or heat treating, heating slugs in a continuous process for forging, heating joints for brazing, continuous heating of moving magnetic strip or wire, and the heating of small nonmagnetic terminals for soft soldering. A very successful recent application of induction heating is the use of radio-frequency power to brighten electrolytic tin plate. In this process the tin surface on the strip is melted continuously with the strip moving at 1,000 feet per minute and with an input of about 1,200 kw of 200-kilocycle power to the heating coil.

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Some of the applications require the heating of magnetic material, such as iron and steel, which usually are easy to heat. Others require the heating of nonmagnetic materials, such as brass or copper, which can be heated less readily, especially when the piece to be heated is small and has a low electrical resistivity.

Since it is impractical to cover the whole field of induction heating in one paper, this paper will be limited to the heating of nonmagnetic materials.

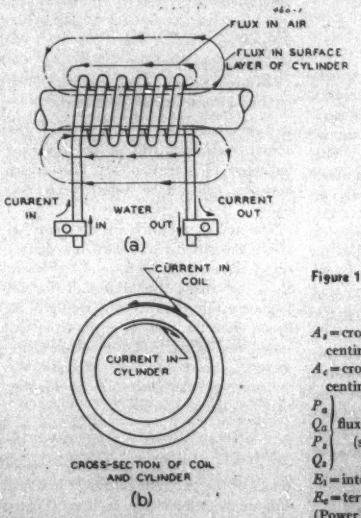

Figure 1. Induction heating of a nonmagnetic cylinder

Almost any problem in induction heating can be resolved into the problem of heating a cylinder, a flat slab or strip, or a surface by a current-carrying conductor near the surface. The following discussion of these three cases, therefore, should enable one to calculate any problem where the material to be heated is nonmagnetic.

List of Symbols

Symbols will be defined throughout the paper the first time they are used, but for convenient reference all symbols are listed here:

f = frequency (cycles per second)
a = radius of a cylinder (centimeters)
d = diameter of a cylinder (centimeters)
ρ = electrical resistivity (ohm-centimeters)
$G_a(K_a a)$ = a function of $(K_a a)$ (Figure 2)
$G_s(K_s t)$ = a function of $(K_s t)$ (Figure 9)
t = thickness of slab (centimeters)
t_w = thickness of cylinder wall (centimeters)
H = peak magnetizing force at surface of piece to be heated (oersteds)
T_c = turns in heating coil
I_c = current in coil (rms amperes)
l_c = length of coil (centimeters)

$$K_a = \sqrt{\frac{8\pi^2 f 10^{-9}}{\rho}}$$

$$K_s = \sqrt{\frac{4\pi^2 f 10^{-9}}{\rho}}$$

ϕ_a = flux inside cyliuder
ϕ_s = flux inside slab
A_a = cross-sectional area of cylinder (square centimeter)
A_s = cross-sectional area of slab (square centimeters)
A_c = cross-sectional area of coil (square centimeter)
P_a, Q_a, P_s, Q_s = flux coefficients for cylinders and slabs (see Figures 3 and 10)
E_1 = internal voltage of coil (rms volts)
E_c = terminal voltage or coil (rms volts)
(Power factor)$_i$ = cos θ_i = internal power factor of coil
cos θ_c = terminal power factor of coil
W_w = total watts into piece to be heated
R = resistance of coil at the frequency used
δ = effective depth of current penetration (centimeters)
f_ρ = see equation 16
f_δ = see equation 17
l_a = axial length of cylinder (centimeters)
l_s = length of slab (centimeters)
x = distance from center line of conductor (centimeters)
I = conductor current (rms amperes)
h_1 = distance from center of conductor to surface of plate
h = equivalent distance defined by equation 27

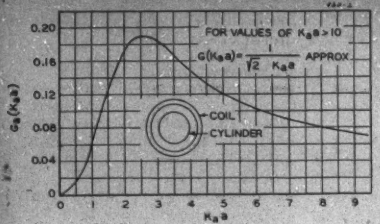

Figure 2 (left). Nonmagnetic cylinder $G_a(K_a a)$ as a function of $(K_a a)$

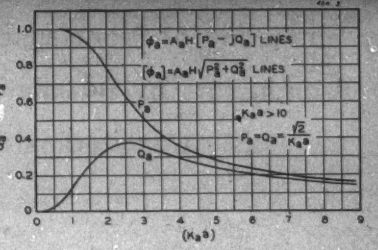

Figure 3 (right). Flux inside nonmagnetic cylinder

K_r = empirical resistance coefficient
R_0 = d-c resistance of solid copper conductor (equation 23)
p_c = inside perimeter of coil (centimeters)
p_w = outside perimeter of work (centimeters)
l_w = axial length of work (centimeters)
ρ_c = resistivity of copper (ohm-centimeters)
ρ_w = resistivity of work (ohm-centimeters)
$W_c = I_c^2 R$ = copper loss in coil (watts)
W = watts per square centimeter or per cubic centimeter

General Consideration of the Induction-Heating Process

When current is caused to flow in the coil (heating coil) surrounding the workpiece, such as the cylinder of Figure 1a, a countercurrent is induced in the workpiece, as illustrated in Figure 1b. The current density is highest at the surface and drops off exponentially inside as shown in Figure 1c. The heating in the piece due to this varying current density is the same as would be caused by the same total integrated current distributed uniformly in a surface layer of thickness δ (Figure 1c). The depth δ is called the effective depth of penetration of current, and, in special cases, it may be used conveniently to calculate induction-heating problems. This paper, however, is concerned with more general methods of calculation, and the depth of penetration concept will be used only in treating the problem of thin-walled cylinders.

Heating of Nonmagnetic Solid Cylinders

The power generated in a nonmagnetic cylinder can be calculated from the equation[1]

$$W = 1/2 H^2 f G_a(K_a a) 10^{-7} \text{ watts per cubic centimeter} \quad (1)$$

where

$$K_a a = a\sqrt{\frac{8\pi^2 f 10^{-9}}{\rho}}$$

f = frequency (cycles per second)
a = radius of cylinder (centimeters)
ρ = electrical resistivity of cylinder (ohm-centimeters)
$G_a(K_a a)$ = a function of $(K_a a)$ involving Bessel's functions and plotted for convenience in Figure 2
H = peak value of magnetizing force at the surface of the cylinder (oersteds)

If the magnetizing coil has closely spaced turns and a length equal to at least 20 times the spacing between the cylinder and the inside diameter of the coil, the end effect of the coil is negligible, and one may calculate H from the equation

$$H = \frac{0.4\pi T_c I_c \sqrt{2}}{l_c} \text{ oersteds} \quad (2)$$

T_c = turns in coil
I = current in coil (rms amperes)
l_c = axial length of coil (centimeters)

If a relatively shorter coil is used, the actual H obtained will be less than that indicated by equation 2. This effect, however, will not be considered in this paper.

The magnetic flux in the air space between the cylinder and the inside diameter of the coil will be $(A_c - A_a) H$ where A_c is the cross-sectional area of the coil (square centimeters) corresponding to its inside diameter, and A_a is the cross-sectional area of the cylinder (square centimeters). Some flux also penetrates the cylinder, and the magnitude of this flux may be calculated from

$$\phi_a = A_a H (P_a - jQ_a) \quad (3)$$

where P_a and Q_a are quantities proportional to the two components of this flux and are plotted for convenience in Figure 3. The total flux linking the coil is then the vector sum of the flux in the air $(A_c - A_a)H$ and the flux in the cylinder $A_a H(P_a - jQ_a)$. If these two are added, one obtains for the total flux

$$\phi_0 = A_a H \left[\left(\frac{A_c}{A_a} - 1 + P_a\right) - jQ_a\right] \text{ lines} \quad (4)$$

or in actual magnitude

$$|\phi_0| = A_a H \sqrt{\left(\frac{A_c}{A_a} - 1 + P_a\right)^2 + Q_a^2} \text{ lines} \quad (5)$$

The voltage induced by this flux in the turns of the coil will be

$$E_1 = \sqrt{2} f T_c |\phi_0| 10^{-8} \text{ volts (rms)} \quad (6)$$

From equations 1, 2, 5, and 6 one may calculate power into the work, coil current, and coil voltage for a variety of conditions. If these quantities are known, one may calculate the corresponding values of what will be termed "internal power factor." The internal power factor will be defined by the equation

$$(\text{Power factor})_1 = \cos\Theta_1 = \frac{W_w}{E_1 I_c} \quad (7)$$

where W_w is the total power in watts put into the work. It is found that the internal power factor is represented by the equation

$$\cos\Theta_1 = \frac{2G_a(K_a a)}{\sqrt{\left(P_a + \frac{A_c}{A_a} - 1\right)^2 + Q^2}} \quad (8)$$

Curves of internal power factor for various values of A_c/A_a are represented by the curves of Figures 4 and 5. The parameter $K_a a$ is used in equation 8 and in plotting the curves of Figures 4 and 5, so as to make them perfectly general and applicable to any frequency and any cylinder. One may calculate values of $\cos\Theta_1$ for $(K_a a)$ values greater than 10 by using the relation

$$K_a a > 10 \quad P_a = Q_a = \frac{\sqrt{2}}{K_a a}$$

$$G_a(K_a a) = \frac{1}{\sqrt{2} K_a a} \quad (9)$$

The voltage E_1 does not include the voltage drop due to the resistance of the heating coil nor to flux which actually passes through the turns (through the copper) of the coil. The coil should always be designed, so that the depth of penetration of flux and current is less than the thickness of the copper from which the coil is wound, and for this condition and for a close-wound coil the voltage drop due to flux inside the copper will be approximately equal to the resistance drop of the coil. The volt-amperes consumed in the copper of the coil on this assumption will be $I_c^2 R(1+j)$ or will have the absolute value $\sqrt{2} I_c^2 R$ where R is the resistance of the coil at the fre-

quency used. The total volt-amperes at the terminals of the coil may be obtained by adding the volt-amperes in the copper of the coil to the volt-amperes E_1I_c, as shown in Figure 6a. This diagram is drawn for the case where the value of volt-amperes in the copper of the coil $\sqrt{2}RI_c^2$ is small compared with E_1I_c. The actual volt-amperes input to the coil is, in this case, only slightly greater than the internal volt-amperes E_1I_c, and the power factor at the coil terminals $\cos\theta_c$ differs only slightly from the internal power-factor $\cos\theta_1$.

One may calculate the total volt-amperes in the coil from the internal volt-amperes E_1I_c and the relation

$$E_cI_c = \sqrt{(E_1I_c\cos\theta_1 + I_c^2R)^2 + (E_1I_c\sin\theta_1 + I_c^2R)^2} \quad \text{volt-amperes} \quad (10)$$

where

$$\cos\theta_1 = \frac{W_w}{E_1I_c}$$

Figure 6b represents approximately the conditions which would be obtained in heating a copper cylinder with the heating coil wound closely around the copper cylinder and with the frequency high enough to make the internal power factor equal to 0.707. This is not a condition likely to be obtained in practice but is included to show that, in an extreme case, the volt-amperes in the copper of the coil may be equal to half the total volt-amperes supplied at the terminals of the coil.

The actual power factor at the terminals of the coil is

$$\cos\theta_c = \frac{W_w + I_c^2R}{E_cI_c} \quad (11)$$

The curves of Figures 4 and 5 are valid only when the cylinder to be heated is equal in length or longer than the heating coil. The internal power factor for the case where the coil is slightly longer than the cylinder, as often will be the case, may be estimated by reducing the values given by these curves in the ratio l_a/l_c where l_a is the length of the cylinder in centimeters.

It is, in general, desirable to operate at a frequency equal to or greater than that which will give the maximum internal power factor. From the curves of Figures 4 and 5 this corresponds to a value of $K_\delta a \geqq 3$. Solution for the corresponding frequency indicates that the frequency to use is

$$f \geqq \frac{114\,\rho 10^6}{a^2} \text{ cycles per second} \quad (12)$$

In some cases, where a very large cylinder of low resistivity is to be heated, this equation may indicate a minimum frequency which is absurdly low from the standpoint of the generator. In such cases, a higher frequency should be used. Also, since a low frequency requires a thick conductor in the heating coil, the mechanical considerations of coil design may force one to use a higher frequency than that which would give a maximum internal power factor. There will be other cases where one wishes to heat only a very thin layer on the surface of the cylinder. In this instance, the frequency should be chosen high enough to make the effective depth of penetration of current defined by the equation

$$\delta = 5{,}030\sqrt{\frac{\rho}{f}} \text{ centimeters} \quad (13)$$

equal to or less than the depth to which heating is desired.

Heating of Hollow Nonmagnetic Cylinders

If one desires to heat a hollow nonmagnetic cylinder having a wall thickness equal to or greater than about one-tenth its diameter, the frequency should be chosen to make δ (equation 13) equal to or less than the wall thickness and use the method of calculation for solid cylinders. The only precaution necessary is to remember that equation 1 gives the average watts per cubic centimeter in a solid cylinder, and, since the total power input to the hollow and solid cylinders will be equal when δ is equal to or less than the wall thickness (t) of the hollow cylinder, the watts per cubic centimeter in the hollow cylinder will be greater than that indicated by equation 1 in the ratio of the cross-sectional area of the solid cylinder to that of the hollow cylinder.

Heating of Thin-Walled Hollow Cylinders

When the wall thickness of a cylinder becomes less than about one-tenth the diameter, one can obtain satisfactory heating with a frequency less than that which makes δ equal to the wall thickness. When the depth of penetration is several times the wall thickness, the cylinder may be considered as a short-circuit d secondary of an air-cored transformer with uniform current density throughout the thickness of the wall. For this condition it can be shown that the power input to the cylinder is

$$W = \frac{1.23f^2d^2t_{wo}H^2 10^{-16}}{\rho^2 + 3.87t_{wo}^2f^2d^2 10^{-16}} \quad (14)$$

watts per square centimeter

d = outside diameter of cylinder (centimeters)

This equation is applied to a thin-walled brass cylinder with the results plotted in Figure 7 (curve B). It is seen that the power input increases rapidly at first, as the frequency is increased, and then becomes constant. The vertical dotted lines indicate the frequency f_p where the input has reached 90 per cent of the value it has in the flat part of the curve and f_δ, the frequency at which the depth of penetration δ becomes equal to the wall thickness. Equation 14, of course, is no longer valid when δ approaches or gets less than the wall thickness, but in this region one may use equation 1 with the approximation $G_a(K_\delta a) =$

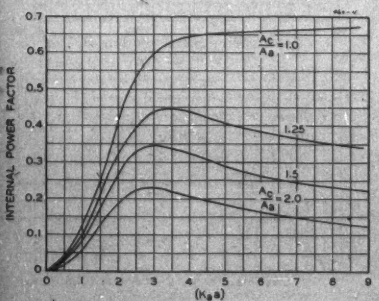

Figure 4. Internal power factor for nonmagnetic cylinder

Cylinder longer than coil

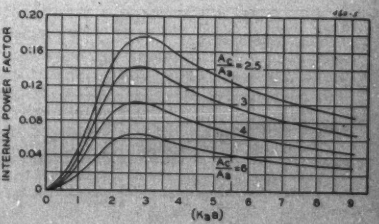

Figure 5 (right). Internal power factor for nonmagnetic cylinder

Cylinder longer than coil

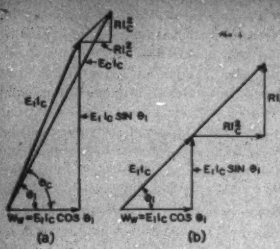

Figure 6. Vector diagrams of volt-amperes in coil

(a). Heating high-resistance material
(b). Heating low-resistance material

$1/\sqrt{2K_s a}$. When rewritten, this equation becomes

$$W = 0.63 \times 10^{-4} H^2 \sqrt{f\rho} \quad \text{watts per square centimeter} \quad (15)$$

Calculation of the hollow brass cylinder with this equation gives curve A (Figure 7). This equation is not valid when δ is greater than the wall thickness of the cylinder but agrees well with equation 14 when $\delta = t_w$. The two curves probably can be joined with the dotted curve shown. It seems, therefore, that one can, with little error, calculate with equation 14 below f_δ and with equation 15 above f_δ. The two frequencies f_ρ and f_δ will come closer together when the ratio of diameter so wall thickness is decreased (Figure 8). These frequencies may be expressed as

$$f_\rho = \frac{153\rho 10^8}{t_w d} \quad (16)$$

and

$$f_\delta = \frac{25.6\rho 10^8}{t_w^2} \quad (17)$$

The ratio of these frequencies is

$$\frac{f_\delta}{f_\rho} = 0.167 \frac{d}{t_w}$$

This shows that the two frequencies coincide approximately when $d/t_w = 6$ and are farther apart the greater the ratio d/t_w. If satisfactory power input can be obtained at the frequency (f_δ), one may as well operate at the lower frequency (f_ρ) or at some intermediate frequency. Only in cases of extreme power input should it be necessary to go to a frequency greater than (f_δ).

Heating of Nonmagnetic Slabs or Strip

A flat nonmagnetic slab, thin in comparison with its width (see cross-section view Figure 9), can be heated by induction, and the power input is given by[3]

$$W = 1/2 H^2 f G_s(K_s t) 10^{-7} \quad \text{watts per cubic centimeter} \quad (18)$$

where

$$K_s t = t \sqrt{\frac{4\pi^2 f 10^{-9}}{\rho}}$$

t = thickness of slab (centimeters)
$G_s(K_s t)$ = a function of $K_s t$ given in Figure 9

As in the case of the cylinder, the magnetizing force may be calculated from equation 2, and the internal voltage E_1 may be calculated from equation 6. The total flux inside the coil for this case will be

$$\phi_s = A_s H \left[\left(\frac{A_s}{A_c} - 1 + P_s \right)^2 - jQ_s^2 \right] \text{lines} \quad (19)$$

or in actual magnitude

$$[\phi_s] = A_s H \sqrt{\left(\frac{A_s}{A_c} - 1 + P_s \right)^2 + Q_s^2} \text{ lines} \quad (20)$$

where

A_s = cross-sectional area of slab (square centimeters)
A_c = inner cross-sectional area of coil (square centimeters)

P_s and Q_s are given by the curves of Figure 10.

The internal power factor will be

$$(\text{Power factor})_1 = \cos \theta_1 = \frac{2G_s(K_s t)}{\sqrt{\left(P_s + \frac{A_s}{A_c} - 1 \right)^2 + Q_s^2}} \quad (21)$$

Values of internal power factor for various values of the ratio A_s/A_c are plotted in Figures 11 and 12. If values taken from these curves are used, the total volt-amperes in the coil and the true power factor at the terminals of the coil may be calculated from equations 10 and 11, respectively.

As in the case of the cylinder, the curves of Figures 11 and 12 are good only if the slab is equal in length or longer than the coil. If the length of the slab is only a little less than the length of the coil, the internal power factor may be obtained by

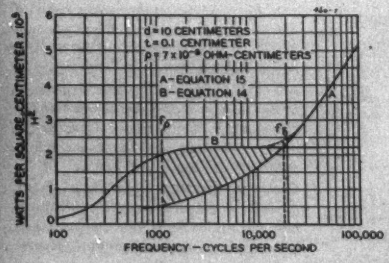
d = 10 CENTIMETERS
t = 0.1 CENTIMETER
ρ = 7 x 10⁻⁶ OHM-CENTIMETERS
A - EQUATION 15
B - EQUATION 14
WATTS PER SQUARE CENTIMETER x 10³
H²
FREQUENCY - CYCLES PER SECOND

Figure 7 (left). Power input to hollow brass cylinder

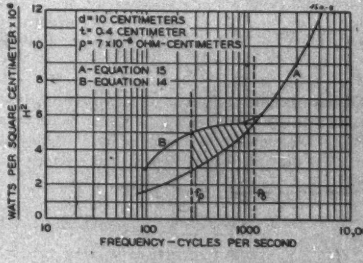
d = 10 CENTIMETERS
t = 0.4 CENTIMETER
ρ = 7 x 10⁻⁶ OHM-CENTIMETERS
A - EQUATION 15
B - EQUATION 14
WATTS PER SQUARE CENTIMETER x 10³
H²
FREQUENCY - CYCLES PER SECOND

Figure 8 (right). Power input to hollow brass cylinder

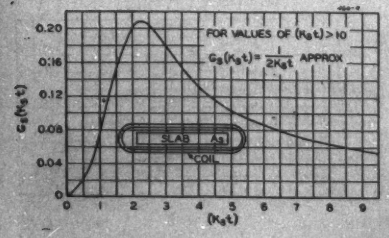

Figure 9 (left). Nonmagnetic slab or strip $G_s(K_s t)$ as a function of $(K_s t)$

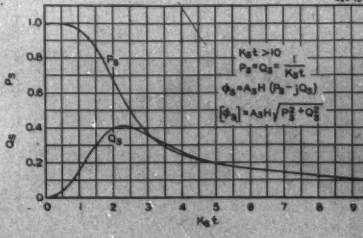

Figure 10 (right). Flux inside nonmagnetic slab or strip

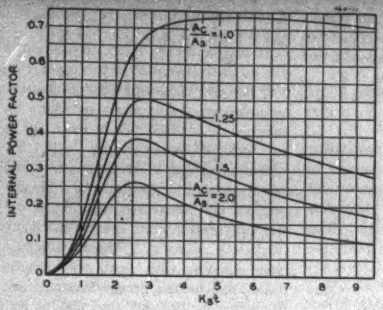

Figure 11 (left). Internal power factor, nonmagnetic slab or strip

Slab or strip longer than coil

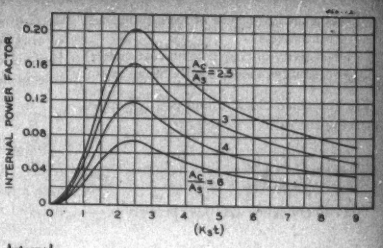

Figure 12 (right). Internal power factor, nonmagnetic slab or strip

Slab or strip longer than coil

reducing the value given by the curves in the ratio l_s/l_c, where l_s is the length of the slab in centimeters.

Since the internal power-factor curves of Figures 11 and 12 peak around 2.5 in the practical range of the ratio A_c/A_s, it can be agreed that the frequency to be used in heating a nonmagnetic slab is determined by the relation $K_s t \geqq 2.5$ or

$$f \geqq \frac{158\,\rho\,10^8}{t^2} \text{ cycles per second} \qquad (22)$$

Heating Cylinders and Slabs of Small Diameter or Thickness

The analysis given previously may be applied to small nonmagnetic wires and thin nonmagnetic sheet, but, because it is difficult to construct a coil to conform closely to the surface of the work in these cases, it is found that the power factor of the heating coil and the efficiency of the process are extremely low. Small-diameter iron wire and thin iron sheet, on the contrary, may be heated quite efficiently, because the magnetic permeability acts to increase the skin effect greatly.

Approximate Calculation of I^2R Loss in Coil—Coil Efficiency

Some work has been done to develop formulas to predict the high-frequency resistance of coils of simple shapes, but these equations are generally tedious to use and are useless for irregularly shaped coils. The writer has found it convenient in the case of coils wound from hollow copper tubing to calculate the high-frequency resistance of the length of tubing used in a coil, as if it were a straight isolated conductor, and then multiply this value of resistance by a factor K_r greater than unity to take into account the fact that the tubing is wound into a coil.

In accordance with the aforementioned material, one may write for the resistance at the frequency (f) of a coil wound from hollow copper tubing[1]

$$R = K_r R_0 (0.038 d\sqrt{f} + 0.25 \text{ ohms}) \qquad (23)$$

K_r = empirical[1] resistance factor
d = outside diameter of tubing (centimeters)
R_0 = d-c resistance of a solid round copper conductor having the same outside diameter and same length as the tubing used in the coil
f = frequency in cycles per second

Tests indicate that the high-frequency resistance of single-layer coils of circular cross-section wound from one-fourth-inch outside diameter to one-half-inch outside diameter copper tubing with diameters from two to four inches and lengths equal to or greater than their diameters may be calculated fairly accurately from equation 23 by using values of K_r given in Figure 15. Some tests made on coils of rectangular or oblong cross section (width more than five times the thickness) showed the resistance of this type of coil to be less frequency sensitive than the coils of circular cross section. The high-frequency resistance of this type of coil may be calculated approximately from equation 23, using the value $K_r = 2.5$.

It must be noted that, for equation 23 to be valid and also to obtain an efficient coil design, the wall thickness of the copper tubing used should be greater than the depth of current penetration, equation 13, at the frequency used. Above ten kilocycles, standard annealed copper tubing with an outside diameter of from one-fourth to one-half inch is satisfactory.

Another method of approximating the copper loss in the coil is to consider the fact that, when the frequency is high enough for satisfactory heating $K_s t \geqq 3$ for cylinders and $K_s t \geqq 2.5$ for flat plates, the current in the work and the ampere turns in the coil per centimeter length are approximately equal. If the coil were close wound of copper strap or a single cylindrical turn of copper, the ratio of loss

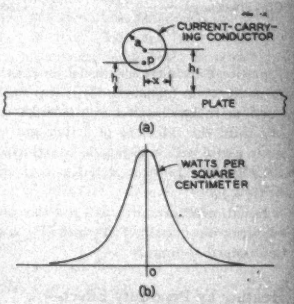

Figure 13. Heating surface of plate by proximity effect

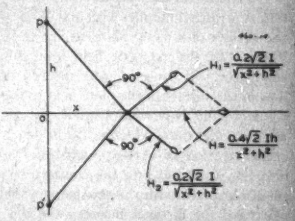

Figure 14. Magnetizing force H from two line conductors

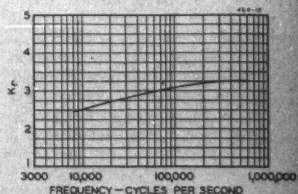

Figure 15. K_r versus frequency for use with equation 23

in the coil to power in the work (nonmagnetic) should be approximately

$$\frac{W_c}{W_w} = \frac{p_c}{p_w} \frac{l_c}{l_w} \sqrt{\frac{\rho_c}{\rho_w}} \qquad (24)$$

p_c = inside perimeter of coil (centimeters)
p_w = outside perimeter of work (centimeters)
l_c = axial length of coil (centimeters)

l_w = axial heated length of work inside coil (centimeters)
ρ_c = resistivity of copper (ohm-centimeters)
ρ_w = resistivity of work (ohm-centimeters)

For the usual close-wound coil of copper tubing the ratio is more nearly

$$\frac{W_c}{W_w} = 1.3\,\frac{\rho_c}{\rho_w}\,\frac{l_c}{l_w}\sqrt{\frac{\rho_c}{\rho_w}} \qquad (25)$$

The coil efficiency can be expressed as

$$\text{Coil efficiency} = \frac{1}{1+\dfrac{W_c}{W_w}} \qquad (26)$$

Equation 25 is fairly accurate if the depth of penetration (equation 13) is less than one-fourth the diameter of a cylinder or one-third the thickness of a slab and is quite useful with equation 26 to estimate the efficiency to be expected in a given heating job.

Equation 26, of course, will give the coil efficiency accurately if W_c and W_w are determined accurately.

Heating by Proximity Effect—Flat Nonmagnetic Plate

If a conductor carrying alternating current is arranged parallel with and close to the surface of a metal plate, as shown in Figure 13a, the magnetic field from this conductor will cause countercurrents to flow in the surface of the plate next to the conductor and to be concentrated approximately under the conductor. If the depth of penetration of current, equation 13, into the plate and into the conductor is small compared with the thickness of the plate and the distance between the conductor and the plate, the problem becomes very similar to the classical electrostatic problem of a charged cylinder near a metal plate.[3,4] The magnetizing force at the surface of the plate is the same as would be caused by two line conductors carrying current in opposite directions, one at (p) height (h) above the surface of the plate and one at (p') distance (h) below the surface. The value of (h) is determined from the height of the center of the conductor (h_1 centimeters) above the surface and the radius of the conductor (a centimeters) and the relation

$$h = \sqrt{h_1^2 - a^2} \text{ centimeters} \qquad (27)$$

Figure 14 shows how the magnetizing forces of these two conductors add to give a resulting magnetizing force at and parallel to the surface of the plate at a point distance (x) from the origin. The value of this magnetizing force (peak) is

$$H = 0.4\sqrt{2}I\frac{h}{x^2+h^2} \text{ oersteds} \qquad (28)$$

I = conductor current (rms amperes)

The heating in a surface for a given value of H parallel to the surface may be calculated from equation 15. If the value of H from equation 28 is substituted in equation 15, the density of heating at the surface of the plate is

$$W = 0.202\times10^{-4}I^2\sqrt{\rho f}\left(\frac{h}{x^2+h^2}\right)^2$$

watts per square centimeter (29)

The curve of Figure 13b shows the power input to the surface calculated from equation 29 for the size of conductor and spacing shown in Figure 13a.

By integrating equation 29 from $x=0$ to infinity in both directions, it is found that the total power input to the plate by a conductor (l) centimeters long is

$$W = 0.316\times10^{-4}\frac{lI^2\sqrt{\rho f}}{h} \text{ watts} \qquad (30)$$

Equations 29 and 30 may be applied also to a single-turn circular coil around a cylinder, provided that the turn conforms closely to the surface of the cylinder. In this case, the value of (l) to use in equation 30 is the circumference of the cylinder. These equations break down in the approximate assumptions on which they are based. They cannot be applied accurately if $h<10\delta$ where δ is calculated for the workpiece from equation 13.

Conclusions

It will be found by an application of the methods described in this paper, that the majority of heating jobs on nonmagnetic workpieces having a minimum dimension of one-half inch or more can be accomplished satisfactorily with frequencies less than 10,000 cycles per second (rotating machine frequencies). Smaller sections may be heated with higher frequencies from vacuum-tube or spark-gap oscillators. Since it is difficult to obtain close coupling with small nonmagnetic pieces, such heating processes usually will be inefficient, although they may be feasible economically.

Hollow cylinders with thin walls often may be heated with frequencies much lower than the frequency required to heat a flat sheet equal in thickness to the wall thickness of the cylinder, as the cylinder acts as a short-circuited secondary winding.

The concept and method of proximity heating is very useful in applying induction heating locally to heat the workpiece. One should remember that, when the frequency is high enough, the currents in the inducing coil or conductor cause image currents to flow in and heat the workpiece.

When it is desired to heat a piece throughout, the minimum frequency indicated by equations 12 and 22 should generally be used; however, if a superficial heating of the surface is desired, a higher frequency should be used. In the latter case, the power input also must be high enough to establish the high temperature gradient necessary at the surface.

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Basic Considerations in Selection of Electric Systems for Large Aircraft

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Synopsis: This paper presents some of the considerations involved in selecting electric systems for large aircraft. Such systems are undergoing intensive development now; consequently it is not possible to give complete answers to all problems which arise. Also, certain parts of the electric systems are subject to military classification and cannot be discussed. Nevertheless it is felt that many engineers, particularly those engaged in the design of such systems, will welcome a brief review of the basic factors involved.

Industrial and central-station experience provide a valuable background for study of aircraft systems. However, too close an adherence to previous practice should not be maintained, since aircraft systems differ in many ways from those of land equipment. The need for minimum weight demands that only those features be included which fundamental considerations show to be necessary or which at least provide benefits that justify the weight involved.

ELECTRIC systems on aircraft have been undergoing continuous evolution since the airplane was invented. Early planes started with a six-volt d-c system patterned after the automobile. Increasing power requirements led, first, to the adoption of 12-volt systems and, later, to the 27-volt* d-c systems which are now in common use. A few airplanes have been operated with 120-volt d-c systems, and some with a-c systems having various frequencies ranging from 60 to 2,400 cycles per second.

The 27-volt d-c electric system for aircraft has done an excellent job to date. It is simple, light, easy to control, reliable, and the electric-shock hazard to personnel is negligible. Therefore, it is proper to ask, "Why not use this system for all planes, especially since wartime conditions already are straining our engineering and production facilities severely?" The answer to this question lies in the fact that while the 27-volt system has proved satisfactory on the larger airplanes such as the *B*17 Flying Fortresses and the *B*24 Liberators, which are now performing in an excellent manner on our fighting fronts, there are new designs on the drafting boards to meet new military requirements. The size, performance, and electric load requirements of these proposed new planes are such that the 27-volt d-c system is no longer adequate or efficient from the standpoint of weight, and consideration must be given to new types of systems for these larger planes.

Since airplanes are designed for many different functions, it is not likely that a single type of system will be the best for every case, even among large planes. Thus, military-plane requirements differ from those of commercial planes. Small plane requirements differ from those of large planes. Altitude, range, nature of mission, and many other factors which are discussed in this paper, affect the choice of an electric system. It is believed that a review of the principal considerations involved will be of value in selecting a system for any given case.

Although the power system is always tailored to the airplane, there are some variables, such as operating voltage and frequency, which can be standardized at certain levels and thus provide the industry with the benefits of standardization. The United States Army Air Forces are contributing to electrical progress in this respect by their standardizing and co-ordinating work. The selection of 400 cycles for a-c systems for certain large military planes is a recent example.[1] A considerable part of this paper deals with problems encountered in such systems.

Purpose and Requirements of Electric System

The purpose of an electric-power system on an airplane is to generate and to distribute electric power to the various pieces of utilization equipment which are required on the airplane. The best system for any particular application is the one which combines most effectively the following features:

1. Maximum reliability under all conditions encountered in operation
   (*a*). Reliability of equipment such as motors and generators.
   (*b*). Service continuity should be maintained automatically even during faults or emergency conditions, insofar as possible.
   (*c*). Minimize hazard to operating personnel, airplane, and equipment.
2. Minimum weight
   (*a*). Minimum installed weight.
   (*b*). Maximum efficiency (fuel economy).
   (*c*). Minimum additional aerodynamic drag for cooling requirements (fuel economy).
3. Minimum space requirements.
4. Simplicity
   (*a*). Ease of operation.
   (*b*). Minimum training time for operating and maintenance crew.
   (*c*). Ease of maintenance in field.
   (*d*). Rapid and accurate checking in field.
   (*e*). Minimize spare-part requirements.
   (*f*). Ease of installation
   (1). Initially.
   (2). Replacement parts.
5. System should not interfere with the performance of the airplane or its equipment in any way, or at least as little as possible.
6. Satisfactory life of all component parts
   (*a*). Minimum frequency of replacement.
   (*b*). Minimum frequency of overhaul.
   (*c*). Minimum frequency of maintenance.
7. Least cost in man-hours and dollars.
8. Utilize existing designs of aircraft accessory equipment as far as is practical.

The desirability of these features is self-evident and, therefore, need not be discussed in detail. However, it might be well to point out that certain factors are interrelated. For example, fuel consumption can be translated in terms of weight for a given-length flight. Ease of operation and maintenance are associated with service reliability et cetera. In diverse applications the various factors have different degrees of importance, and it is necessary to compromise on a system which provides the best over-all characteristics for the particular application under consideration.

The evaluation of weight and efficiency of aircraft accessory equipment is particularly important in long-range aircraft, since fuel must be provided not only to operate it but also to carry the fixed weight of the equipment plus any additional structural-weight requirements introduced by it and the necessary added fuel. Any increase in fixed weight tends

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* Sometimes referred to as 24-volt or 30-volt systems. Equipment for such systems is usually designed as follows: generators, 30 volts; motors, 27 volts; relay and contactor coils, 18-29 volts. Utilization-equipment nameplates are marked 24 volts. Voltage regulators are adjusted to hold 28.5 volts at the bus.

to decrease the pay load per pound of fuel for a given airplane and range. For example, for a 20-hour cruising range, approximately one-half pound of fuel is required to carry one pound of fixed weight over this range.[1] In addition, the engine fuel rate is approximately one-half pound of fuel per horsepower-hour. On the basis of an assumed over-all system efficiency of 50 per cent (which includes generator losses, motor losses, and distribution losses), this means that 20 pounds of fuel are required to obtain an electric-motor output of one horsepower continuously during a 20-hour flight. A gain of ten per cent in the over-all efficiency of the system thus would result in a saving of 3½ pounds of fuel per horsepower of continuous motor load. Thus, for this case, if the increase in over-all system operating efficiency of ten per cent can be made for an increase of system fixed weight of less than 3½ pounds per motor horsepower, a net gain can be shown. If, however, the increased weight exceeds the weight of the fuel-saving possible, the higher-efficiency equipment is not justified.

Operating Conditions

For satisfactory results, apparatus used in aircraft systems should be designed to withstand the entire range of conditions encountered in use. Many of these conditions are encountered in industrial designs, but the combination of conditions, together with the weight and space requirements, is practically unique to airborne equipment. These conditions are as follows:

1. Ambient-temperature range.
2. Altitude range.
3. Exposure to dust, sand, salt, fungus, humidity, and corrosion.
4. Vibration.
5. Flight-attitude range.
6. Acceleration.

Numerical values can be assigned to these quantities only for specific airplanes. These values should be prescribed by the airplane designing engineer to meet his particular requirements.

For military planes, in addition to these requirements, it is desirable to design a system which has the minimum exposure and vulnerability to damage resulting from enemy gunfire. This means that damage in one part of the system should not be communicated to other parts of the system.

Driving Power for Generators

Some possible sources of driving power for aircraft generators are as follows:

1. Accessory drive shaft from main engine.
   (*a*). Bolted directly to a pad on the main engine.
   (*b*). Separately mounted and driven by a flexible shaft from main engine.
2. Auxiliary gas engines or gas turbines.
3. Exhaust-gas turbines.
4. Steam turbine using exhaust heat.
5. Wind-driven generators.

When a generator is bolted directly to the main engine on a suitable accessory power take-off pad, certain limitations are encountered which must be met by the generator design to enable it to fit into the space available without putting too great a strain on the engine housing. Thus the diameter, length, and bending moment (at the generator flange) are limited. Also, the generator must be designed to withstand the relatively severe vibration encountered when it is mounted directly on the engine.

These limitations dictate the maximum physical size and weight of the generator that can be mounted on a given engine.[12]

By mounting the generator separately and providing a flexible-shaft drive from the main-engine take-off pad to it, these limitations are removed, but the additional weight and space requirements of the separate mounting and flexible shaft must be considered.

Accessory-shaft drive from the main engine, with a generator bolted directly to a take-off pad on it, is probably the most common form of drive today. This is because it provides an adequate, reliable source of power for little added weight and because it operates with good fuel economy. In a multiengine plane in which several generators are used they may be operated either isolated or in parallel. D-c generators with suitable characteristics and voltage regulators may be paralleled even though the several engines may be running at different speeds. If constant-frequency a-c generators are used, they must be driven through some form of variable-ratio drive, which is governed to maintain substantially constant speed in spite of variations in engine speed. Furthermore, conventional alternators, if operating in parallel, must run at exactly the same speed to maintain synchronism. This entails rather severe requirements for the governors and variable-ratio drives,[2] although this problem is simplified to a certain extent by the use of free-wheeling between the drive and the generator.

Auxiliary gas engines provide a flexible source of power that does not interfere with the main power, and can be made of any required rating. The main disadvantages to such engines, at present, are their weight, space requirements, lower fuel economy (compared with that of the main engines), and relatively poorer reliability. In comparing fuel economy for a given flight, it is necessary to take into account the efficiency of a variable-ratio drive if used, and main-engine fuel economy as compared with that of the auxiliary engines. Also, the load duty cycle has an important bearing on this calculation. Where high altitude is involved, auxiliary engines either must carry their own superchargers or be supercharged from the main-engine supercharger. Auxiliary engine-driven generators are relatively easy to operate in parallel whether alternating or direct current.

The exhaust-gas turboalternator looks promising for certain applications in which a sufficient amount of energy can be extracted from the exhaust to furnish the electrical requirements without impairing the main-engine performance, as, for example, in medium-altitude cargo planes. Generators can be operated readily in parallel when employing this type of drive. In some high-altitude aircraft in which exhaust-gas energy is

Figure 1. Side view of main-engine-mounted air-blast-cooled d-c aircraft generator

4,550/8,000 rpm; 30 volts; 300 amperes, continuous; 450 amperes, two minutes

Weight, 48 pounds; diameter, six inches; length, 14 inches

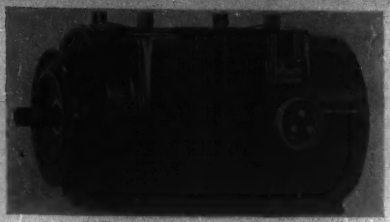


Figure 2. Air-blast-cooled d-c aircraft generator, separately mounted, but driven from the main engine

5,400/11,200 rpm; 120 volts; 8¾ kw, continuous; 14½ kw, five minutes; 17½ kw, five seconds

Weight, 78 pounds; size, eight inches by eight inches by 14½ inches long

used for supercharging cabins as well as engines, and also for deicing, there is not sufficient available energy remaining to provide driving power for a large electrical demand under all conditions of flight.

Waste heat from the exhaust can be utilized by a closed-cycle steam turbine. Such a drive naturally requires a boiler and condenser, as well as a turbine, and consequently may be difficult to justify on a weight basis. Since it operates on waste heat, however, it shows up well from the standpoint of fuel economy. For military use, a condenser having a large exposed surface would be objectionable because of its vulnerability. There are many other technical problems, such as condenser freezing at low ambients, that will have to be solved before this type of drive becomes useful in aircraft.

Wind-driven generators are used extensively on small airplanes for furnishing small amounts of power. However, they are very inefficient aerodynamically, and therefore are not competitive with other forms of drive when large amounts of power are required.

From the foregoing considerations it seems that accessory-shaft drive from main engines is the best power source available at present for the majority of large airplanes.

Types of Power Systems

The power system may take any one of a variety of forms, several of which are listed below.

1. Generate direct current and utilize direct current at substantially the same voltage, either 27 or 120 volts.

2. In some cases a dual-voltage d-c system may be used, with all the small equipment put on the 27-volt system and the larger equipment on the 120-volt system.

3. Generate variable-frequency alternating current, and rectify to utilize as direct current.

4. Generate constant-frequency constant-voltage alternating current; utilize part as alternating current, and rectify part for use as direct current.

5. Generate variable-frequency variable-voltage alternating current (voltage proportional to frequency), and utilize as generated.

6. Generate both alternating current and direct current, and utilize as generated.

7. Generate variable-frequency constant-potential alternating current; rectify and then invert to constant-frequency constant-potential alternating current.

There are many more possible combinations, but this group includes the varieties which have been used, or most seriously considered, to date.

The 27-volt d-c system has the advantages of simplicity and low hazard to operating personnel. It is satisfactory for most small and medium-sized planes. Where large amounts of electric power or large planes requiring long circuits are involved, this system becomes inadequate because of the large weight of the conductor required as a result of the limitations of conductor heating and line voltage drop. Commutation and brush wear at high altitudes are a maintenance problem, although great strides are being made toward minimizing it. This system is very widely used today.

The 120-volt d-c system overcomes the problem of excessive conductor size to a large degree, but introduces additional problems of commutation at higher voltages, particularly in small motors. It also introduces the problems of high-altitude higher-voltage switchgear and control. For energy-storage magnitude normally used for aircraft, batteries for 120-volt systems are quite heavy compared to batteries for 27-volt systems. The higher voltage is very suitable for large hoisting equipment and other similar apparatus which may be required in some cargo planes. Such systems have been used successfully and are to be included in certain aircraft now being constructed. Low voltage (27 volts) is usually required, in addition, for certain instruments, controls, and lamps (high-voltage lamp filaments do not resist vibration as well as low-voltage lamps of the same wattage).

The dual-voltage d-c system combines the advantages of the two d-c systems previously discussed with a slight added complexity.

Supplying direct current by rectifying the output of variable-frequency generators[1,2] makes it possible to use an alternator in place of the d-c generator. The absence of a commutator permits an alternator of much greater kilowatt capacity to be built for mounting directly on the main-engine take-off pad, within the prescribed limits of bending moment and diameter. Ratings as high as 32 kw have been built within these envelope limitations, which previously were occupied by six- to nine-kw d-c generators. This system also eliminates the need for high-current brushes on the generator, and therefore minimizes the maintenance problem. However, brushes are still used on the slip rings, so that the brush problem, although considerably reduced, is not eliminated entirely. The weight of a dry-plate rectifier, or transformer and rectifier, is added but this is compensated partially by the lower weight of the alternator as compared with a d-c generator of equivalent rating. Such systems are now under intensive development.

The constant-frequency a-c system offers a suitable source of power for most loads but requires variable-ratio transmission and governors if it is to be operated from the main engines. These naturally add appreciably to the weight. However, the advantages[1,2] of this system are sufficiently great so that now it is being given intensive development.

Use of auxiliary engines with this system eliminates the need of variable-ratio transmissions, but it is expected that such transmissions will weigh appreciably less than auxiliary engines. In general, the use of alternating current minimizes commutation and brush-wear problems, thereby decreasing maintenance. It does not eliminate these problems, however, since both exciters and slip rings may require brushes, although they do not present as difficult a problem as on completely d-c systems.

Variable frequency, with voltage proportional to frequency is satisfactory only for certain loads such as a-c torque motors. The difficulty with this system is that motors operating from it run at a speed depending upon the frequency, which varies widely. This would result in unsatisfactory performance of many devices. Other equipment, such as lights, radios, suit heaters, and so forth, normally operate at constant voltage and consequently special provision must be made for them. For these reasons, this

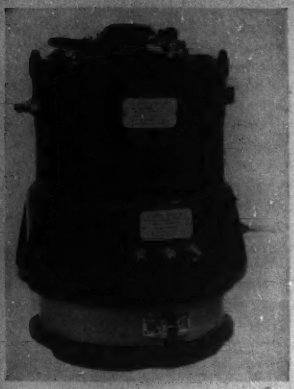


Figure 3. Dual-voltage d-c aircraft generator for use with auxiliary engine. The low-voltage generator also serves as a starting motor for the auxiliary engine

4,000 rpm; 120 volts, 6.75 kw and 28.5 volts, 2.0 kw; continuous; both machines are rated for 50 per cent overload for five minutes

Weight, 125 pounds, including coupling and cooling fan; diameter, 11 inches; length, 19½ inches

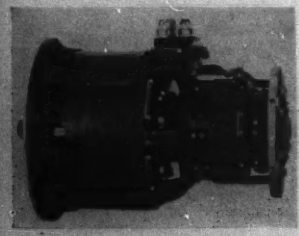


Figure 4. Air-blast-cooled a-c aircraft generator with direct-mounted exciter. Portion of housing and air duct removed to show exciter and collector rings. Driven from main engine at constant speed through variable-ratio transmission. Generator and transmission are mounted separately from the main engine

6,000 rpm; three-phase 208Y/120 volts, 400 cycles, 40 kva, continuous; 60 kva, five minutes; 80 kva, five seconds; 0.75 power factor

Weight, 80 pounds, including exciter; diameter, 9¼ inches; length, 17¼ inches

type of system is used only for certain special applications.

Dual systems a-c and d-c, with separate power sources, combine certain advantages of other systems but increase complexity. They are used for special applications.

The rectified-inverted constant-frequency constant-voltage a-c system dispenses with the necessity for variable-ratio drives where main engines are used as the driving source. It also eliminates any need for synchronizing equipment and simplifies parallel operation. However, because of the weight of conversion equipment required and lower efficiency resulting from multiple transformation losses, this system does not seem very attractive at present.

The 27-volt d-c system is used most commonly in present-day medium and large aircraft, and it is likely to continue to be an important voltage level. Higher-voltage systems such as 120 volts direct current or 208 volts constant-frequency alternating current, supplemented by a small amount of 27-volt d-c distribution, appear promising for larger aircraft requiring greater amounts of auxiliary electric power. Much of the equipment for these higher-voltage aircraft systems is undergoing active development at the present time.

Figures 1, 2, 3, 4, and 5 show generators which have been developed for various systems.

Selection of Voltage

The selection of system operating voltage depends primarily upon the following factors, most of which can be evaluated in terms of weight.

1. Transmission distance.
2. Power to be transmitted.
3. Available utilization equipment.
4. Weight of reliable generation, distribution, and utilization apparatus.
5. Line-voltage-drop limitations.
6. Generation, distribution, and utilization of power at one voltage, insofar as possible, to avoid weight of transformers or converters.
7. Safety to personnel[2] and plane.
8. Creepage, insulation,[2,3] and arc-interruption problems.

In general, for increased power and increased transmission distances, higher voltage is desirable to minimize the weight in the power conductors. Mechanical limitations establish lower limits to wire size in aircraft wiring, and there is no gain in increasing the voltage beyond the point at which the minimum wire size can take care of a large part of the loads. As the voltage is increased, the required insulation increases, and consequently the point of diminishing returns is reached rapidly.[3] Also, the hazard to the operator increases with increasing voltage.[2] It is therefore, desirable, to select a practical voltage level no higher than that which will give minimum over-all weight.

The influence of system voltage on the weight of the power-distribution-system copper based on the same power, transmission distance, and current density is illustrated by the accompanying table:

Systems	Per Cent
27 volts, direct current, with ground return	100
120 volts, direct current, with ground return	22.5
120 volts, direct current, two-wire	45
208Y/120 volts, three-wire, three-phase, alternating current, 0.75 power factor	30

Alternating Current Versus Direct Current[1,9]

The functions of the utilization equipment and the operating conditions will largely determine whether alternating current or direct current should be used. For example, radios normally require alternating current, whereas direct current is best adapted to many control devices.

For large high-altitude aircraft, alternating current is so promising that a great deal of development work on equipment for such systems is now in progress. The simplicity, low maintenance, safety, and light weight of a-c motors and generators tend to favor its use. Commutation and brush-wear problems are minimized. Because of commutator-design limitations, development of very high-speed motors appears more promising with alternating current. Also, certain equipment requires alternating current, which can be obtained directly from an a-c system, thereby eliminating the need for converters. Alternating current has the advantage that various desired utilization voltages can be obtained by transformers, which are lighter and simpler than d-c voltage converters.

Direct current has the advantage that generators may be driven directly from engine take-off shafts without variable-ratio constant-speed transmissions. For sizes up to 12 kw they can be mounted directly on the engine pad. Also, paralleling of d-c generators is relatively easy. D-c motors are capable of greater peak torques and starting torques than are a-c motors of the same weight. They are, also, more adaptable to speed control. Single-wire distribution, with ground return and single-pole switching, is possible with direct current on metal airplanes. Wiring weight is less, at the same voltage, because it is not necessary to transmit the wattless kilovolt-amperes

associated with alternating current at power factors other than unity. Energy storage, by use of batteries, is possible with direct current.

Sufficient data are not yet available for a complete weight comparison between a-c and d-c systems, but they are being accumulated as equipment designs are developed. Any such comparison must consider the weight of all equipment, such as generators, motors, wiring, control, variable-ratio transmissions, circuit breakers, contactors, fuses, et cetera, and also the weight of fuel required to supply the losses in the system for the duration of the flight.

Figure 5. Oblique view of main-engine-mounted air-blast-cooled d-c and a-c aircraft generator

4,000/8,000 rpm; 200 amperes; 30 volts direct current. 800/1,600 cycles, single phase, ten amperes; 120 volts alternating current

Weight, 47 pounds; diameter, six inches; length, 13½ inches

Selection of Frequency if Alternating Current Is Used

The selection of frequency[1] depends to a large extent upon the type of utilization equipment used in the airplane. In general, selection should be made for minimum weight of the entire electric system which will provide satisfactory performance. It is desirable to operate motors at high speeds up to the limits of good bearing performance, since this tends to minimize equipment weight even when reduction gears are required. The frequency should be high enough to permit motor speeds in the order of 8,000 to 12,000 rpm and, yet, not so high as to require, at such speeds, too many motor poles for efficient motor design. Much of the d-c motor-driven apparatus used on present-day aircraft is designed for motor speeds of 8,000 rpm. This has been found satisfactory for continuous operation of grease-packed ball bearings. For intermittent operation, grease-packed ball bearings in small sizes operate satisfactorily up to 12,000 rpm. It is desirable to utilize these same speeds insofar as possible, to avoid unnecessary redesign of gear-reduction mechanisms, and to make use of maximum speed permitted by practical bearing design. It is desirable, therefore, to select a frequency which will provide these speeds.

The frequency should be selected so that speeds up to 24,000 rpm are not ruled out, since such speeds may be desired for the lightweight turboalternators which hold promise for the future. Such machines probably would be designed with oil-pressure lubrication on the bearings. Again, certain gyroscopic instruments may require speeds of this order.

For motors that are not geared, the frequency should be such that at least the majority of these motors can be designed with a number of poles (preferably four, six, or eight) which will result in the required speed with an efficient, lightweight design. The frequency should be high enough so that a sufficient number of speed steps are available in the desired motor-speed range to permit flexibility in application without requiring an excessive number of poles.

Iron-core transformers become lighter with increasing frequency within practical limits, so that this becomes a consideration in applications where many transformers are used.[11]

There is a considerable amount of 115-volt 400-cycle single-phase a-c electronic equipment now in use in aircraft. From the standpoint of interchangeability and elimination of conversion equipment it is desirable to be able to operate this electronic equipment directly from the power system.

If too high a frequency is used, skin effect in conductors and eddy current and penetration effects in iron cores increase the weights of wiring and equipment. Except for frequencies well above 400 cycles, however, these effects are not significant for most wire sizes and equipment designs used in aircraft. For example, for all wire sizes equal to or smaller than AN–8,* the skin and proximity effects at 400 cycles increase the losses by less than one per cent. This includes the majority of wires on the 208Y/120-volt system now contemplated. For larger wire sizes, skin and proximity effects increase considerably. Thus, for AN–0 it is 11 per cent, and for AN–0000 it is 30 per cent at 400 cycles. These figures are based on minimum practical spacings with insulated aircraft cables.

Polyphase Versus Single Phase in A-C Systems

Single-phase systems offer simplicity in wiring and switching equipment. Single-phase motors require capacitors or other means of phase splitting in order to obtain starting torque. Polyphase motors and generators are lighter than single-phase motors because they utilize available winding space more effectively.** Systems with three or more phases will transmit power with less copper than systems with a fewer number of phases. Generally there is no advantage in using more than three phases. Of course, single-phase loads can be operated from three-phase systems satisfactorily, provided they are reasonably well distributed among the phases to avoid excessive unbalance. Single-phase motors will be used only for very small incidental loads where three-phase power is available.

Types of Alternators for A-C Systems

The alternator may take any one of several forms, some of which are as follows:

1. Conventional design, with either rotating field or rotating armature.
2. Inductor alternator, having rotating salient poles excited by a stationary winding.
3. Induction alternator, having a squirrel-cage rotor.

The conventional design requires two sets of slip rings and brushes for the rotating field, and three or four sets for the rotating-armature three-phase machine, depending on whether or not the neutral is brought out. The light weight of these generators, their stability when used with direct-connected exciters, and ease of control make the conventional type of machine preferable for most cases.

The inductor alternator requires no slip rings or brushes of any kind, but its weight is from 40 to 50 per cent greater than that of the conventional type, so that it is not being developed actively for main-power generation.

The induction alternator also requires no slip rings, and can be built with a simple, sturdy rotor similar to that in a

* Army-Navy Standard Aircraft Wire Size. Approximates corresponding American Wire Gauge size.

** Except in very small sizes (1/8 horsepower and less) when it may not be practical to use three-phase windings because of space limitations.

squirrel-cage induction motor. For this type of generator, parallel operation is greatly simplified, since the machine takes its excitation from the system; consequently, synchronization and precise speed control are not required, although a variable-ratio drive is required. Where such alternators are used, however, excitation must be furnished by other synchronous machines on the system, either alternators or synchronous condensers. The weight and vulnerability of these additional necessary machines is a disadvantage. Also, the ability of the system to recover from electrical disturbances tends to be less than for systems of comparable weight using conventional generators with direct-connected exciters. The starting problem also must be given special consideration with this system, as special devices are required for this purpose.

Types of Excitation Systems for A-C Systems

If conventional alternators are used, excitation can be furnished by:

1. A direct-connected self-excited exciter.
2. Transformation and rectification from the a-c system.
3. D-c generators or batteries on the plane, if available.

The direct-connected exciter is preferred because this arrangement makes each unit independent of other units on the system. It also provides a relatively "stiff" system which will not collapse completely under excessive load or even under solid-fault conditions, since a fault or load does not reduce the available excitation. The disadvantage of this system is the added weight and space required by the exciter, and the fact that brushes and commutator are present on the exciter. However, since the energy requirements for the exciter are relatively small, this does not appear to be a serious problem. A direct-connected exciter also results in lighter voltage-regulating equipment, since only exciter field current need be regulated, and standard voltage regulators that already have been developed for aircraft can be used with only slight modifications.

Excitation from rectifier supply must depend either upon residual in the alternators or upon the presence of an independent d-c system for initial build-up. A collapse of the a-c system through a sustained solid three-phase fault will mean a loss of excitation and, consequently, the inability to burn the fault clear. It also makes a system that is less stiff and has a maximum current point beyond which both the voltage and excitation will collapse unless the overload or fault is removed very quickly. This system introduces starting problems, particularly at low ambient temperatures at which the rectifier resistance increases. If high residual is incorporated to assist in starting, the regulator range required is increased considerably.

Excitation from an independent d-c system has the disadvantage that damage in the d-c system (a fault, for example) is communicated immediately to the a-c system as a loss of excitation, thereby tending to depress the a-c voltage also. It also requires heavier nonstandard voltage-regulating equipment compared with that for direct-connected exciters.

Manner of Grounding

Most 27-volt d-c systems are solidly grounded to eliminate one wire in metal planes. This not only reduces the weight of wiring but also the exposure to hazards such as gunfire. One disadvantage of grounding is that any energized conductor accidentally coming in contact with the metallic skin of the plane constitutes a fault on the system.

Higher-voltage d-c systems probably also will be grounded to eliminate one wire. While a perfectly isolated system would involve less hazard to operating personnel than a grounded system, there is always in practice, a certain amount of capacitance and leakage between conductors and ground and also the possibility of accidental grounds, so that it is doubtful whether grounding significantly affects electric-shock hazard.

When both voltages of a dual-voltage d-c system are grounded, a third voltage is made available, which is either the sum or difference of the other two voltages, depending on whether like or unlike polarities on the two systems are grounded.

Some of the usual reasons for a-c system grounding, such as protection against transient overvoltages (on systems above 600 volts) and possible improvement of lightning-arrester protection for overhead transmission systems, are not important in aircraft.

Grounding of aircraft systems has the advantage that accidental faults either are cleared immediately or otherwise detected so that faults are not likely to go unnoticed. Ground detectors can be used, of course, with an ungrounded system, but they will not indicate the location of the fault. Accidental grounds, in an ungrounded system, which are not detected constitute a hazard, since the next ground on another conductor puts a fault on the system. Grounding the neutral of a three-phase a-c system on a metal airplane provides the equivalent of a four-wire system, so that single-phase loads can be operated conveniently at line-to-neutral voltage. Furthermore, if polyphase motors are operating on the system and their neutrals are grounded, they will continue to operate reasonably well if one circuit is accidentally open-circuited (by enemy gunfire, for example). This is considered to be an advantage on certain types of equipment for military planes.

Grounding of the neutrals of a-c generators increases the line-to-ground fault current of the system. If the utilization equipment is ungrounded, this ground fault current can be limited to any desired value by a suitable resistor or reactor in the generator neutral. However, in cases where the motors in the utilization equipment have solidly grounded neutrals, such a current-limiting device does little to limit the line-to-ground current. See Figure 6.

Whereas grounding the neutral solidly increases the fault currents which must be handled by the switchgear, it also prevents displacement of the neutral so that the switch voltage is reduced; hence the weight of switching equipment is not necessarily increased. This is shown by Figure 7. Higher ground-fault currents speed up the "burning clear" of ground faults and make it more difficult to obtain a "welded" fault.[4] They shorten the fault clearing time for fuses which may be used in the circuits.

Grounding of one phase of a three-phase a-c system has been given consideration, but is not being planned for any specific projects to date. The weight of one wire is saved, of course, by this means, and switches may be only two pole. However, line-to-neutral voltage is not available then, switchgear must handle 73 per cent higher voltage per pole, electric-shock hazard is somewhat increased by the higher line-to-ground voltage, and an increase of radio and interphone interference resulting from the presence of unbalanced fields may be introduced.

Power-Factor Correction

Capacitors frequently are used for power-factor correction in industrial a-c systems. The benefits are reduction in line losses, reduced wire size to transmit a given amount of power, and increased

power available from a given-size generator. In higer-hfrequency a-c systems such as the 400-cycle system, the weight of capacitors required per kilovolt-ampere of correction is substantially less than that in 60-cycle systems of the same voltage. Capacitor weights of the order of $1^1/_4$ pounds per kilovolt-ampere, in sizes of one-half kilovolt-ampere and larger, are now available for 208-volt 400-cycle systems, and future developments may reduce this considerably.

In spite of these relatively low weights for corrective capacitors for 400-cycle a-c systems, it is doubtful if they will have widespread application in aircraft, because the lines are relatively short and the loading intermittent. Preliminary calculations on certain systems indicate that the savings in wire weight, losses, and generation are offset by the weight of the capacitors. Such a calculation can be made for any given system to determine whether or not power-factor correction is justified. In general, the lower the power factor, the more effective are the capacitors, so that for some very low-power-factor apparatus they can be justified. It usually does not pay to correct to unity power factor, however.

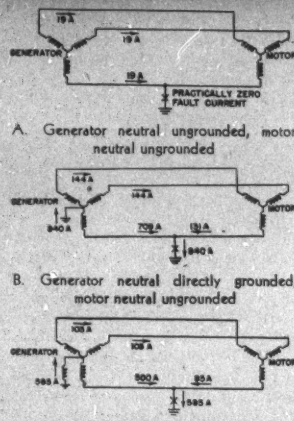
In addition to the weight and economy, there are certain other factors that should be considered in any particular case in determining whether or not power-factor correction is desirable. The capacitors occupy a certain amount of space and, therefore, tend to increase the vulnerability of the system to gunfire, for example, and to accidental fault. In addition, where parallel operation is involved, the system stability is reduced if full advantage is taken in reduction of possible generator size.

Parallel Versus Nonparallel Operation

When several generators are used, parallel operation provides certain advantages and has certain drawbacks. The most important of these are given in the following tabulation, and apply to both a-c and d-c systems.

ADVANTAGES

1. Greater motor-starting capacity.
2. Reduction of time and magnitude of voltage disturbances from faults, motor starting, or loss of generation.
3. More effective use of spare capacity, so that smaller or fewer generators can be used without excessive load-transfer switching.
4. Greater ability to burn faults clear.[4]
5. Continued operation of load equipment following engine or generator failure does not require any automatic transfer equipment nor any immediate attention from the operator.



A. Generator neutral ungrounded, motor neutral ungrounded

B. Generator neutral directly grounded, motor neutral ungrounded

C. Generator neutral grounded through a reactor (X_n=5%), motor neutral ungrounded

D. Generator neutral directly grounded, motor neutral directly grounded

E. Generator neutral grounded through a reactor (X_n=5%), motor neutral directly grounded

Assumptions:
Generator rated current = 100 amperes
Motor rated current = 100 amperes
Generator internal voltage = 100 per cent

Reactances	Generator (Per Cent)	Motor (Running Light) (Per Cent)
Positive sequence, X_1	20	500
Negative sequence, X_2	20	20
Zero sequence, X_0	5	5

Figure 6. Effect of neutral grounding and neutral impedance on line-to-ground fault current

DISADVANTAGES

1. Increases weight and complexity of control, especially for alternating current. Equipment for synchronizing is required for paralleled a-c systems. Constant-speed transmissions for a-c systems require accurate governing if generators are to be paralleled (with auxiliary-engine drive this problem is not so severe). For d-c generators, voltage regulators must control within very close limits to permit satisfactory parallel operation. Furthermore, equalizing circuits must be designed and maintained carefully, especially if a large number of generators is used.
2. Routine monitoring of load balance and (for alternating current) reactive kilovolt-ampere balance may be required.
3. Faults and other disturbances affect entire electric system.
4. Heavier switchgear is required because of the greater fault currents available.
5. Co-ordination problems relating to circuit protective equipment are more exacting because of the possibility of variable generation, and the higher currents involved.

No general rule can be made since the selection here depends, to a large extent on the type of utilization equipment and the nature of the operations involved. Both parallel and nonparallel operation have been used successfully in airplanes. A-c systems which are subject to loss of synchronism through fault or other disturbances should be designed so that they can operate either parallel or nonparallel.

At present, considerable development work is being pursued in order to establish the practicability and performance requirements of parallel operation of aircraft alternators from engine take-off drives using variable-ratio transmissions.

Synchronizing Methods for Paralleling A-C Generators[2]

If the system selected is alternating current, and parallel operation is desired, the question of how best to synchronize the generators is introduced. There are several methods available. These are:

1. Automatic synchronizing, with full voltage on both running and incoming machines.
2. Automatic synchronizing, with reduced or zero voltage on the incoming machine.
3. Manual synchronizing, with either full, reduced, or zero voltage on the incoming machine.
4. Random manual synchronizing at full voltage.

It is probable that purely random synchronizing, without any attempt to match the phase angles of the generators before switching them together, will cause undue momentary disturbance to the system voltage. At present, considerable development is in progress on equipment for fully automatic synchronizing, which will parallel a-c generators with practically no resulting disturbance. However, this involves appreciable added

weight and complexity in control equipment, so work is being done also on simpler and lighter automatic equipment, which will connect generators together with little or no excitation on the incoming machine, building its excitation up immediately after switching. This will cause some disturbance to the system voltage, but may be acceptable in some cases. In general, automatic synchronizing is expected to be preferable to manual means, since manual synchronizing requires considerable attention and skill on the part of the operator.

Size and Number of Generators

The number of generators is selected by considerations of vulnerability and amount of stand-by power desired for emergency use. Generators should be distributed among engines as far as is practicable, so that loss of one engine will not cause too great a loss of generation. From the standpoint of weight economy, it is important that the airplane not be burdened with excessive generating capacity. Stand-by capacity of 100 per cent is considered to be the upper limit, even for military combat planes.

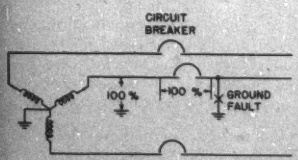
It is desirable to select generators which individually are large enough to start the largest single load (or group of loads which must be started simultaneously). This may seem unnecessary when parallel operation is used, but is a desirable feature, since operation from one generator may be required in an emergency.

The electric loads can be grouped into two main categories, namely:

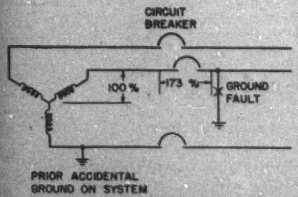
1. Those essential to flight.
2. All other loads.

These other loads have varying degrees of importance in different planes but they are always subordinate to those in classification 1. In the selection of the amount of stand-by power, this division and the degree of importance of other loads is an important consideration, since service to loads of lesser importance may be discontinued in an emergency. It is desirable, of course, to lay out the system so that the amount of generation left on a crippled plane that can still fly will be sufficient to bring the plane back safely.

In totaling the electric load on an airplane, duty cycle and time of operation are important considerations, since many of the loads are highly intermittent in nature. The peak load requirement must be met with suitable stand-by, of course. Short-time overload ratings are given on aircraft generators to permit proper selection for such conditions.



A. Grounded system, clearing of line-to-ground fault



B. Ungrounded system, clearing of line-to-ground fault. (As shown, this fault will not cause breaker tripping unless an accidental ground already exists on the system)

Figure 7. Effect of grounding on recovery voltages. (Voltages are given in per cent of normal line-to-ground voltage)

Use of Auxiliary-Engine-Driven Generators to Supplement Main-Engine-Driven Generators

An auxiliary set, either hand- or battery-started, is of value for ground operations such as electrical testing and starting the main engines.

Such a set usually is not supercharged. However, at low altitudes it could be used to furnish some essential power in an emergency, provided that the unit is installed in such a manner that it can be started after hours of flight at extremely low temperatures.

In cases where the weight of such a unit might be considered excessive, it can be treated as disposable load, provided that the airplane always is to be based where auxiliary ground power is available or a battery is used that will handle all essential ground operations, such as engine starting in cases where electric starters are used.

Satisfactory, small, independent, lightweight superchargers, suitable for use with small auxiliary engines in aircraft which must operate at high altitude, and which are subject to sudden changes of load, have not yet appeared. However, it is possible to utilize the first stage (turbine- or gear-driven) of the main-engine supercharger for this purpose. Another possibility is to utilize air from the cabin supercharger (or cabin waste air), if available in sufficient quantity to meet the requirements, and if the supply is dependable under all conditions of operation.

Use of an Auxiliary D-C System With Main A-C Power System

Certain control functions, instruments, and other small electric loads are handled most economically from a low-voltage d-c system and, consequently, it seems desirable to maintain such a system even in cases where the main power is alternating current. Such a system may be derived from the main a-c system by suitable transformation and rectification. It may or may not have a battery. If no battery is used, it is important to arrange the circuits in such a manner that the a-c system can be started, preferably without the use of auxiliary ground power.

Distribution-System Design[7]

The fundamental principles of good distribution-system design are the same for all types of systems. Protective equipment for generators, busses, lines, and utilization equipment for d-c and a-c systems, of all voltages used so far in aircraft, are available or are being developed. It is beyond the scope of this paper to discuss the various means and devices for insuring reliable distribution-system performance with minimum weight. This weight should be evaluated in each specific case when selection among types of power systems is to be made.

Conclusions

There are many conflicting requirements for different applications, but the need for higher-voltage higher-power systems has required industry to develop apparatus rapidly to meet this demand. Consideration of the previously enumerated conditions and requirements has resulted in the selection of the 208Y/120-volt 400-cycle three-phase grounded-neutral system as one standard for a-c systems in aircraft. This choice represents a compromise of the many factors involved. All parts of these systems are now undergoing intensive development. These developments entail an enormous amount of engineering and development work, as practically every piece of apparatus in the generation, distribution, and utilization systems has to be designed especially for 400 cycles

and aircraft use, which requires lightweight, vibration-resistant designs operable at high altitude.

The selection of 208Y/120 volts, 400 cycles, and three phases as a voltage and frequency level for a-c systems in aircraft appears to be a particularly happy choice, in that this voltage is high enough to transmit the required amounts of electric power economically over the distances required by the largest planes and high enough for the largest amounts of auxiliary electric power in any planes now being designed or likely to appear in the near future. This voltage is low enough so that no unusual difficulties are experienced in switching, even at high altitudes. It is below the range where corona at high altitude becomes troublesome.[6] Again, it is low enough so that it does not constitute a very serious hazard to operating personnel from accidental contact. Four hundred cycles is somewhat less hazardous in this respect than 60 cycles.[3]

A considerable amount of equipment in military planes is now served by 115-volt 400-cycle single-phase inverters or dynamotors operating from the 27-volt d-c system. This apparatus can be served directly from the 208Y/120-volt 400-cycle system, which probably will be adjusted to hold about 205 volts at the generator bus so that the utilization-equipment voltage will be about 200Y+115. In this way, no transformers will be required to serve this apparatus, and the need for dynamotors or inverters will be eliminated, with a consequent saving in weight.

The proposed system will retain a relatively small 27-volt d-c system derived from the main a-c system for control, instruments, and other small loads as required. Generators will be of the conventional type with direct-connected exciters.

Some work has been and is being done on 120-volt d-c equipment. It is probable that dual-voltage d-c systems (27 and 120 volts) will make their appearance in medium-altitude cargo or transport airplanes where commutation and brush problems are not so severe and the equipment is of the nature of hoisting equipment or similar apparatus for which this voltage is well adapted.

Thus the aircraft industry will have the following voltage levels for which apparatus already is available or is being designed:

1. For very small planes, such as private planes, 6- or 12-volt d-c systems.

2. For small and medium-sized planes, 27-volt d-c systems.

3. For large medium-altitude cargo or transport planes, dual-voltage (27- and 120-volt) d-c systems.

4. For large high-altitude long-range planes, 208Y/120-volt three-phase 400-cycle a-c systems.

These voltage levels will probably meet the needs of the aircraft industry for some time to come.

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Starting Windings for Single-Phase Induction Motors

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MEMBER AIEE

Synopsis: Methods are given to enable the design engineer to determine the best starting winding and the best capacitor, reactor, or resistor required to meet any specified requirements. The methods given have been in actual use by design engineers for over 12 years, and are as useful today as they were when developed. Simple circle diagrams depict graphically the principles involved in the method. Some practical observations, based on experience, are given. A calculation form, with sample calculations, is also included.

CALCULATION METHODS given in this paper supply the designer with a tool for computing the starting performance of any given winding; they also enable him to determine the particular auxiliary winding best suited to meet any given set of requirements. In this paper use is made of the equivalent-circuit concept so popular in technical writing. Also, use is made of the concepts of *open-circuit reactance* and *short-circuit reactance*, introduced by Branson in 1912,[4] followed by Kron,[5] Boothby,[1] Puchstein and Lloyd,[6] Himebrook,[7] Trickey,[8] and by the author in previous papers.[2,9]

Locked-Rotor Impedance of a Single Winding

A necessary preliminary to the determination of starting performance is the determination of the locked-rotor impedance. Very roughly, the locked-rotor impedance is

$$\dot{Z}=(r_1+r_2)+j(x_1+x_2) \qquad (101)$$

This simple relationship usually is not accurate enough for fractional-horsepower motor design. A more accurate expression, given as equation 2 in Appendix I, is

$$\dot{Z}=(r_1+r_3C_r)+jXC_R \qquad (102)$$

The coefficients C_r and C_R are defined in equations 9 and 10 and plotted in the form of curves in Figure 2. It will be observed that the apparent rotor resistance is always less than the actual, while the apparent short-circuit reactance is always greater than the ideal. In the derivations that follow, the apparent impedance, as defined above, is used consistently.

Starting-Torque Equation for Single-Phase Induction Motors

C. R. Boothby[1] gave the following equation for the starting torque of a single-phase induction motor with an auxiliary winding. Expressed in the notation of this paper, and with one modification, his equation is

$$T_s=\frac{1.88p}{f}Kr_{2m}'I_mI_a\sin(\theta_m-\theta_a) \qquad \text{(ounce-feet)} \quad (103)$$

The modification from this original equation is the use of the apparent rotor resistance, r_{2m}', instead of the actual rotor resistance, r_{2m}. (See Table I.) Morrill[3] has given a more rigorous derivation of the starting-torque equation; equation 14 of his paper is exactly reducible to equation 103. This starting-torque equation is applicable to all types of single-phase induction motors having two windings in space quadrature; it is the basis for the remainder of this paper.

Starting Windings for Split-Phase Induction Motors

The design of the main or running winding usually is fixed by considerations of efficiency and breakdown torque. The problem generally is to find the best possible companion starting winding; in this connection, considerable help will be given by Figure 3, which shows in a graphical manner how various changes in auxiliary winding affect the starting torque and line current.

The magnitude and phase position of the locked-rotor current of the main winding is computed from equation 102 and laid out in Figure 3 as OA. A certain number of turns and distribution of the starting winding is assumed, fixing the reactance, X_a'. The problem now is to determine the optimum resistance for this assumed starting winding. The semicircle AGB is constructed with $AB=E/X_a'$. Now, take any point on this semicircle, C, for example; the line AC represents the magnitude and phase position of the auxiliary-winding current, I_a, for some as yet unknown value of R_a and the assumed value of X_a'. In other words, the semicircle is the locus of the end of the vector I_a as R_a is varied, all other quantities remaining constant. The line current is OC or the vector sum of the main- and auxiliary-winding currents. The starting torque is proportional to the length of CK, since

$$CK=I_a\sin(\theta_m-\theta_a)$$

The maximum starting torque that can be obtained by varying R_a and leaving all other terms fixed occurs when CK is a maximum in length. This condition is fulfilled by point D on the diagram, where D is midway between A and G on the arc. The maximum starting torque per ampere of line current is obtained when the ratio CK/OC is a maximum, which occurs when the line OC is tangent to the semicircle. In the figure, C is actually the point for maximum starting torque per ampere.

This diagram shows a considerable increase in line current between points C and D for an almost negligible gain in starting torque. The diagram is most helpful in visualizing the factors involved and their interrelationships. It is not recommended as a routine design procedure; algebraic equations are better

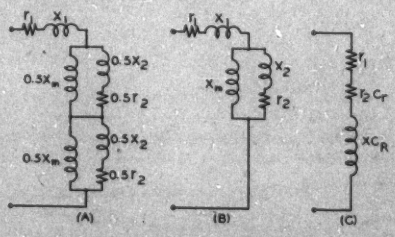

Figure 1. Equivalent circuit of a single-phase induction motor at standstill (revolving-field theory)

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suited to this purpose. Such equations may be developed from the diagram. First, two distinct starting windings will be recognized: a *maximum-torque winding* as indicated by point *D*, and a *maximum-torque-per-ampere* winding, as indicated by point *C*.

Maximum-Torque Windings for Split-Phase Motors

For the maximum-torque winding

$$\widehat{AD} = \frac{\widehat{AG}}{2}$$

therefore, by plane geometry

$$\angle DAH = \theta_a = \frac{\theta_m}{2} \qquad (104)$$

By trigonometry

$$\cot \theta_a = \cot \frac{\theta_m}{2} = \frac{1+\cos\theta_m}{\sin\theta_m} = \frac{1}{\sin\theta_m} + \cot\theta_m$$

or

$$\frac{R_a}{X_a'} = \frac{R_m + Z_m}{X_m'} \qquad (105)$$

or

$$R_a = \frac{X_a'}{X_m'}(R_m + Z_m) \qquad (106)$$

The total resistance in the primary of the starting winding is

$$r_{1a} = R_a - r_{2a}' \qquad (107)$$

Equation 106 gives the total value of resistance that must be used in the primary winding to obtain a maximum-torque winding as shown by point *D* in Figure 3.

At the AIEE North Eastern District technical meeting in Rochester, N. Y., in 1931, P. H. Trickey presented a student paper on starting windings in which, by differentiating a form of equation 103 and finding the value of r_{1a} to give a maximum T_n, he found that

$$r_{1a} = K^2(r_{1m} + Z_m) \qquad (108)$$

which is substantially equivalent to equation 106. The comparison is interesting. Trickey's student paper goes on to investigate the maximum-torque winding quite extensively. Unfortunately, however, this winding is seldom the best one to be used, as it results usually in the use of more copper in the starting winding than necessary and sometimes results in low pull-up torque.

Maximum-Torque-Per-Ampere Windings for Split-Phase Motors

Point *C* in Figure 3 defines a maximum-torque-per-ampere winding. It is shown in Appendix II that the value of R_a, corresponding to point *C*, is

$$R_a = \frac{R_m X_a' + Z_m\sqrt{X_a'(X_m' + X_a')}}{X_m'} \qquad (109)\ (20)$$

Equation 109 gives the total value of resistance that must be in the auxiliary

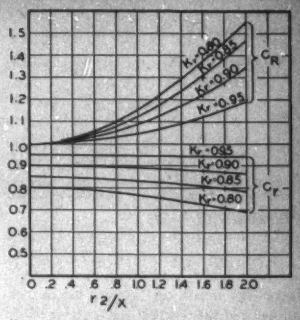

Figure 2. Variation of C_R and C_r with change in motor-design constants

phase to obtain a maximum-torque-per-ampere winding; the total resistance that must be used in the primary winding is found by subtracting r_{2a}', as done in equation 107.

Calculation of a maximum-torque-per-ampere winding using the form of Figure 6 can be simplified by rewriting equation 109 in the form

$$X_m' R_a - R_m X_a' = Z_m\sqrt{X_a' X_{ma}'} \qquad (109a)$$

More useful than the above are equations giving the required values of R_a and X_a' in terms of the desired locked-rotor current, since the latter quantity usually is specified. For a maximum-torque-per-ampere winding designed so that the total locked-rotor current in the line is I_L, it is

Table I. Motor Constants for Locked-Rotor Conditions

	Windings Only		Windings With External Impedance in Series		
	Main Winding	Auxiliary Winding	Auxiliary Winding With Resistor	Auxiliary Winding With Capacitor	Main Winding With Reactor
1. Applied volts	E	E	E	E	E
2. External impedance	0	0	Z_r	Z_c	Z_R
3. Real component of external impedance	0	0	R_r	R_c	R_R
4. j component of external impedance	0	0	X_r	X_c	X_R
5. Rotor resistance, referred to primary winding concerned	r_{2m}	r_{2a}	r_{2a}	r_{2a}	r_{2m}
6. Apparent rotor resistance	$r_{2m}' = C_r r_{2m}$	$r_{2a}' = C_r r_{2a}$	$r_{2a}' = C_r r_{2a}$	$r_{2a}' = C_r r_{2a}$	$r_{2m}' = C_r r_{2m}$
7. Resistance of primary winding	r_{1m}	r_{1a}	r_{1a}	r_{1a}	r_{1m}
8. Real component of total impedance	$R_m = r_{1m} + r_{2m}'$	$R_a = R_{1a} + r_{2a}'$	$R_{ar} = R_a + R_r$	$R_{ac} = R_a + R_c$	$R_{mR} = R_m + R_R$
9. Ideal reactance	X_m	X_a			
10. Apparent reactance, or j component of total impedance	$X_m' = C_R X_m$	$X_a' = C_R X_a$	$X_{ar}' = X_a' + X_r$	$X_{ac}' = X_a' + X_c$	$X_{mR} = X_m' + X_R$
11. Total impedance	$Z_m = \sqrt{R_m^2 + X_m'^2}$	$Z_a = \sqrt{R_a^2 + X_a'^2}$	$Z_{ar} = \sqrt{R_{ar}^2 + X_{ar}'^2}$	Z_{ac}	Z_{mR}
12. Current in one phase	$I_m = E/Z_m$	$I_a = E/Z_a$	$I_{ar} = E/Z_{ar}$	$I_{ac} = E/Z_{ac}$	$I_{mR} = E/Z_{mR}$
13. Angle of lag of current behind the voltage	θ_m	θ_a	θ_{ar}	θ_{ac}	θ_{mR}
14. Defining equation for angle of lag	$\tan\theta_m = \frac{X_a'}{R_m}$	$\tan\theta_a = \frac{X_a'}{R_a}$	$\tan\theta_{ar} = \frac{X_{ar}'}{R_{ar}}$	$\tan\theta_{ac} = \frac{X_{ac}'}{R_{ac}}$	$\tan\theta_{mR} = \frac{X_{mR}}{R_{mR}}$

shown in Appendix II that the starting winding has the following constants:

$$R_a = \frac{R_m + Z_m(I_L/I_m)}{(I_L/I_m)^2 - 1} \quad (110)\ (25)$$

and

$$X_a' = \frac{X_m'}{(I_L/I_m)^2 - 1} \quad (111)\ (18)$$

where I_m = locked-rotor current in main winding only.

Of the equations given so far, 110 and 111 are the most useful. They completely specify a starting winding that gives the maximum starting torque per ampere of line current for a given main winding and specified value of total locked-rotor current. In using these equations, however, the current density in the starting windings must be checked, for sometimes these formulas lead to an overworked starting winding.

In general, the maximum-torque-per-ampere winding results in less weight of starting-winding copper and works the starting winding harder than the maximum-torque winding. Practical windings often are a compromise between the two, and generally favor the former, as far as possible.

Alternate Formula for Starting Windings for Split-Phase Motors

The circle diagram of Figure 3 is based upon the assumption that R_a is the variable and all other factors remain constant. H. E. Ellis has derived an interesting equation from equation 103, assuming X_a' to be the variable and all other factors remain constant. He assumed

$$K \propto \sqrt{(X_a'/X_m')} \quad (112)$$

K thus becomes a variable in his analysis.

Equation 103 can then be rewritten

$$T_s = \text{constant}\left(\sqrt{\frac{X_a'}{X_m'}}\right)\cdot\left(\frac{X_m'R_a - R_mX_a'}{Z_m(R_a^2 + X_a'^2)}\right) \quad (113)$$

$$\frac{dT_s}{dX_a'} = X_a'^2 - 3X_a'^2\left(\frac{X_m'R_a}{R_m}\right) - 3X_a'R_a^2 + \frac{X_m'R_a^2}{R_m} = 0 \quad (114)$$

Solving for X_a', one finds that the only practical root is

$$X_a' = \frac{R_a}{R_m}\left(X_m' - 2Z_m \sin\frac{\theta_m}{3}\right) \quad (115)$$

An excellent procedure is to calculate R_a from equation 110, and X_a' from equation 115, in place of equation 111. This procedure is perhaps the best but, of course, the current density in the starting winding has to be watched.

Resistance-Start Motors

A resistance-start motor differs from a split-phase motor only in that an external resistance is used in series with the starting winding. In such a case, R_a as used in the preceding expressions, must be assumed to include the resistance of the external resistor as well as the resistance of the motor windings.

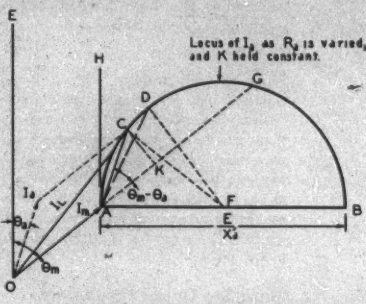

Figure 3. Starting-torque diagram for a split-phase motor

Capacitor-Start Motors

The locked-rotor conditions of a capacitor-start motor are illustrated in Figure 4.* Both main and capacitor windings are assumed. The magnitude and phase position of the main-winding current I_m is constructed as OA. A value of capacitance has been assumed, and the capacitor-phase current I_a is laid out similarly as AC. Now, if we make the assumption that R_{ac}, the total resistance in the capacitor phase, remains constant, the locus of point C, as the external microfarads vary, will be the semicircle shown having a diameter of E/R_{ac}. This assumption is not strictly correct, for R_{ac} will vary slightly as the microfarads are changed (because R_c does), but it leads to convenient and useful formulas, and the slight variation in R_{ac} with microfarads can be taken into account, as will be shown later.

The point for maximum starting torque is D, found by drawing a tangent parallel to OA. It is shown in Appendix III that the maximum starting is obtained when

$$-X_{ac}' = \frac{R_{ac}}{R_m}(Z_m - X_m') = \frac{R_{ac}R_m}{Z_m + X_m'} \quad (116)\ (28)$$

* Some time after these analyses were made, it was discovered that W. J. Morrill had shown a similar diagram as Figure 4 of his paper,[2] though he did not develop it to the extent done in this paper.

(X_{ac}' from equation 116 is always a negative number.)

The reactance of the external capacitor is simply

$$X_c = X_{ac}' - X_a' \quad (117)$$

where X_{ac}' is found from equation 116. (Since X_{ac}' and X_c are both negative, $-X_c$ is the arithmetical sum of X_{ac}' and X_a'.) Equation 116 is similar to the one given by Boothby,[1] who derived his expression by a different method. The value of microfarads obtained from equation 116 may be called *maximum-torque microfarads*. Almost without exception, this value of microfarads is too great for a practical capacitor-start motor.

A much better value of microfarads is that which gives the maximum starting torque per ampere, as indicated by point C in Figure 4. In Appendix III it is shown that the starting torque per ampere is a maximum when

$$X_{ac}' = \frac{X_m'R_{ac} - Z_m\sqrt{R_{ac}(R_m + R_{ac})}}{R_m} \quad (118)\ (36)$$

Thus, the procedure of finding the number of microfarads that will yield the maximum starting torque per ampere of line current when the main winding is fixed, is as follows:

(*a*). Compute the algebraic value of X_{ac}' from equation 118. The result will be a negative quantity.

(*b*). Compute the external capacitive reactance from equation 117.

(*c*). Microfarads $= \dfrac{10^6}{2\pi f(-X_c)}$

(*d*). If the value of microfarads so found is such that its effective resistance, R_c, is considerably different from the assumed value of R_c, steps (*a*), (*b*), and (*c*) can be repeated using the correct value of R_c to obtain R_{ac}. This refinement generally is unnecessary, however.

Calculation of microfarads for maximum starting torque per ampere using

the form of Figure 6 can be simplified by rewriting equation 118 in the following form:

$$X_m'R_{ac}-R_mX_{ac}'=Z_m\sqrt{R_{ac}R_{mac}} \qquad (118a$$

Equations are developed in Appendix III for R_{ac} and X_{ac}' in terms of the constants of the main winding and the locked-rotor line current. These expressions are

$$X_{ac}'=\frac{X_m'-Z_m(I_L/I_m)}{\left(\frac{I_L}{I_m}\right)^2-1} \qquad (120)\ (40)$$

$$R_{ac}=\frac{R_m}{\left(\frac{I_L}{I_m}\right)^2-1} \qquad (121)\ (34)$$

These equations are similar to 110 and 111 for split-phase motors. However, the author has not found them so useful as their companion formulas for split-phase motors. One reason is that usually it is practicable and more advantageous to use a lower value of R_{ac} than equation 121 indicates. More important, though, is the fact that neither equation 120 nor 121 gives any clue as to the proper number of turns to use in the auxiliary winding. Hence these two equations are of an interest more academic than practical.

Best Winding for a Capacitor-Start Motor

Selection of an auxiliary winding and capacitor for a capacitor-start motor requires the exercise of judgment and experience that cannot be expressed wholly in the form of equations. Attention must be paid to the voltage across the capacitor, not only for the locked-rotor condition, but also for all speeds up to switch-operating speed. Usually it

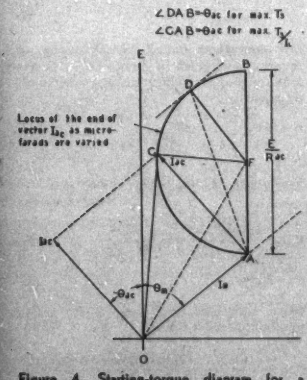

Figure 4. Starting-torque diagram for a capacitor-start motor

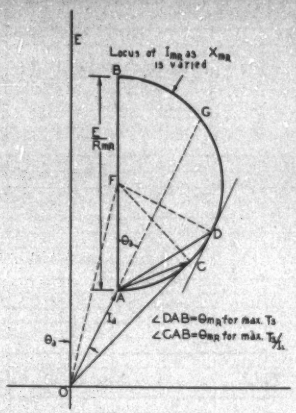

Figure 5. Starting-torque diagram for a reactor-start motor

will be necessary to make a number of trial designs before selecting the best one to meet the conditions specified. One procedure is to assume a starting winding, compute the microfarads for maximum starting torque per ampere from equation 118, then with this value of capacitance calculate starting torque, line amperes, and capacitor volts. If the starting torque is low, it may be necessary to do some combination of the following:

1. Increase the number of microfarads.
2. Increase the resistance of the rotor.
3. Increase the number of turns in the auxiliary winding.

If the capacitor voltage is high, it may be necessary to do some combination of the following:

1. Increase the microfarads.
2. Increase the resistance of the auxiliary winding.
3. Increase the rotor resistance.

If the locked-rotor current is high, it may be necessary to do one or the other of the following:

1. Increase the rotor resistance.
2. Increase the number of turns in the auxiliary winding and decrease the number of microfarads.
3. Reduce the breakdown torque by increasing the turns of the main winding.

Use of the microfarads for maximum starting torque from equation 116, as shown by point D in Figure 4, may result in some of the aforementioned difficulties; more microfarads almost certainly will give trouble. It is best, usually, to work between points C and D in Figure 4, which means that the value of capacitance chosen should lie between the values given by equations 116 and 118.

Reactor-Start Motors

Reactor-start motors are generally similar to split-phase motors except that, during the starting period, an external reactor is connected in series with the main winding. A circle diagram of the starting conditions of such a motor is given in Figure 5. In Appendix IV, it is shown that the external reactance for maximum starting torque is

$$X_R=\frac{R_aR_{mR}}{Z_a-X_a'}-X_m' \text{ or } \frac{R_{mR}}{R_a}\times(Z_a+X_a')-X_m' \qquad (122)\ (44)$$

Likewise it is shown that the external reactance for maximum starting torque per ampere is

$$X_R=\frac{X_a'R_{mR}+Z_a\sqrt{R_{mR}(R_a+R_{mR})}}{R_a}-X_m' \qquad (123)\ (50)$$

Locked-Rotor Line Current for Motor With Auxiliary Winding

If two impedances, $\dot{Z}_m$ and $\dot{Z}_a$ are connected in parallel to a voltage E, the resultant line current, by Kirchhoff's laws, is

$$I_L=\frac{E(\dot{Z}_m+\dot{Z}_a)}{\dot{Z}_m\dot{Z}_a}$$

$$=I_m\frac{(\dot{Z}_m+\dot{Z}_a)}{\dot{Z}_a}=I_m\frac{\dot{Z}_{ma}}{\dot{Z}_a} \qquad (124)$$

or

$$I_L=I_m\frac{Z_{ma}}{Z_a} \qquad (125)$$

where

$$Z_{ma}=\sqrt{(R_m+R_a)^2+(X_m+X_a)^2} \qquad (126)$$

Equation 125 is a most convenient expression for calculating the line current. It appears in modified forms in equations 19, 35, and 48.

A Practical Calculating Form

For determination of the best auxiliary windings and best winding and capacitor combinations, the calculating form shown in Figure 6 was devised with the assistance of H. E. Ellis; it has been of enormous practical value. It was designed for both split-phase and for capacitor-start motors. When all the constants of both windings (and external capacitor, if any) are known, the calculations are made in the order listed except that three

STARTING PERFORMANCE CALCULATIONS

CALCULATION #			1	2	3	4	5	6	7	8
(20) = EITHER SIN (16) / (19) OR (5) x (13)										
	RESISTANCE	CAPACITOR								
1	r_{1m}	r_{1m}	1.47	1.47	1.47					
2	r_{2m}'	r_{2m}'	2.67	2.67	2.67					
3	R_m	R_m	4.14	4.14	4.14					
4	X_m'	X_m'	3.72	3.72	3.72					
5	Z_m	Z_m	5.57	5.57	5.57					
6	—	R_c	0.93	0.93	0.93					
7	r_{1a}	r_{1a}	4.83	4.83	4.83					
8	r_{2a}'	r_{2a}'	3.67	3.67	3.67					
9	R_a	R_{ac}	9.43	9.43	9.43					
10	—	$-X_{ac}'$	6.48	6.71	-4.21					
11	X_a'	X_a'	5.14	5.14	5.14					
12	—	$-X_c$	11.62	11.85	9.35					
13	Z_a	Z_{ac}	11.42	11.56	10.31					
14	θ_m	θ_m	42.0		42.0					
15	θ_a	$-\theta_{ac}$	34.5		24.1					
16	(14)−(15)	(14)+(15)	76.5		66.1					
17	$X_m'R_a$	$X_m'R_{ac}$		35.1						
18	R_mX_a'	$-R_mX_{ac}'$		27.8						
19	(17)−(18)	(17)+(18)		62.9						
20	SIN $(\theta_m-\theta_a)$	SIN $(\theta_m-\theta_{ac})$	0.972	0.977	0.915					
21	×K	×K	1.172	1.172	1.172					
22	×1.86 p/f	×1.86 p/f	0.1252	0.1252	0.1252					
23	$\times r_{2m}'$	$\times r_{2m}'$	2.67	2.67	2.67					
24	$\times I_m$	$\times I_m$	20.6	20.6	20.6					
25	$\times I_a$	$\times I_{ac}$	10.05	9.96	11.16					
26	$=T_s$	$=T_s$	78.7	78.5	82.5					
27	R_{ma}	R_{mac}	13.57	13.57	13.57					
28	X_{ma}	X_{mac}	2.76	2.99	0.49					
29	Z_{ma}	Z_{mac}	13.84	13.89	13.57					
30	$I_c=I_m Z_{ma}/Z_a$	$I_c=I_m Z_{mac}/Z_{ac}$	25.0	24.8	27.1					
31	CM/Ia	$E_c=I_{ac}X_c$	116.9	118.0	104.2					
32		$V_{AC}=I_{ac}X_c$								
33		MFD	228	224	284					
34		T_s/I_L	3.15	3.18	3.04					

1/3 HP 115 VOLTS 60 CYCLES 4 POLES CALC. REF. _____ DATE 11-5-43

TYPE CAP START SIGNATURE I. A. Veinott L- _____

Figure 6. Form for calculating starting performance

items may be omitted; these items are 14 to 16, inclusive, or 17 to 19, inclusive, depending upon the preference of the calculator. Such a set of calculations is shown in column 1.

For calculating maximum-torque-per-ampere windings for capacitor-start motors, the following procedure has been found very useful and helpful. First, the known constants of the two windings are entered in lines 1, 2, 4, 7, 8, 11, 21, 22, 23. A value of R_c for line 6 is assumed and entered. The following lines are then computed in the order named: 3, 5, 9, 17, 27. Line 19 is then computed by making use of equation 118a. Then, the remaining items are computed and filled in in this order: 18, 10, 12, 13, 20, 24 to 33, inclusive. This procedure yields the microfarads for maximum starting torque per ampere, starting torque obtained, locked-rotor currents in each winding and in the line, and capacitor volts and volt-amperes. Whereas X_{ac}' may be computed from equation 118 and the items of Figure 6 calculated in consecutive order, the procedure outlined reduces considerably the numerical computations involved. Such a set of calculations is made in column 2. It is seen that the capacitor for column 1 was already chosen so as to give practically maximum starting torque per ampere. As a comparison, X_{ac} for maximum starting torque was computed, and complete calculations made as listed in column 3.

Maximum-torque-per-ampere windings for split-phase motors can be computed by a similar procedure, using equation 109a, but usually it is best to determine these windings from equations 110 and 111, or 110 and 115.

Symbols (See, Also, Table I)

r_1 = primary resistance

r_2 = secondary resistance, referred to primary

C_r = $\dfrac{\text{apparent rotor resistance}}{\text{actual rotor resistance}}$ defined by equation 9

C_R = $\dfrac{\text{apparent total reactance}}{\text{ideal total reactance}}$ defined by equation 10

X = ideal short-circuit reactance. This is the short-circuit reactance the motor would have if the secondary resistance were zero

X_0 = open-circuit reactance

T_s = starting torque, in ounce-feet

I_L = total locked-rotor current

P = number of poles

K = winding ratio = $\dfrac{\text{number of effective conductors in auxiliary winding}}{\text{number of effective conductors in main winding}}$

f = frequency in cycles per second

$\dot{Z} = R + jX$

$Z = \sqrt{R^2 + X^2}$

Appendix I

Locked-Rotor Impedance of Main Winding of a Single-Phase Induction Motor

In Figure 1 is shown the equivalent circuit of a single-phase induction motor under locked-rotor conditions. From inspection of this figure, the apparent impedance of the motor is

$$\dot{Z} = r_1 + jx_1 + \frac{(jx_m)(r_2 + jx_2)}{r_2 + j(x_m + x_2)} \tag{1}$$

which can be reduced, by ordinary algebraic processes, to the form

$$\dot{Z} = (r_1 + r_2 C_r) + (jXC_R) \tag{2}$$

where

$$C_r = \frac{x_m^2}{(x_1 + x_m)^2 + r_2^2} \tag{3}$$

$$C_R = \frac{1 + \left(\dfrac{x_1 + x_m}{X}\right)\left(\dfrac{r_2}{x_2 + x_m}\right)^2}{1 + \left(\dfrac{r_2}{x_2 + x_m}\right)^2} \tag{4}$$

X = "ideal short-circuit reactance"

$$= x_1 + \frac{x_2 x_m}{x_2 + x_m} \tag{5}$$

The equivalent circuit corresponding to equation 2 is given in Figure 1C. If the primary and secondary leakage reactances are equal

$x_1 = x_2$

Let

$X_0 = x_1 + x_m = x_2 + x_m$ = open-circuit reactance (6)

$$K_p = \frac{x_m}{x_m + x_1} = \frac{x_m}{x_m + x_2} = \sqrt{\frac{X_0 - X}{X_0}} \tag{7}$$

$$K_r = K_p^2 \tag{8}$$

When equations 6, 7, and 8 are used, equations 3 and 4 become

$$C_r = \frac{K_r}{1 + (r_2/X_0)^2} = \frac{\text{apparent rotor resistance}}{\text{actual rotor resistance}} \tag{9}$$

$$C_R = \frac{1+\frac{r_2}{X}\frac{r_2}{X_2}}{1+(r_2/X_2)^2} = \frac{\text{apparent total reactance}}{\text{ideal total reactance}} \tag{10}$$

Equations 9 and 10, when substituted into equation 2, give the identical results reported in equations 1, 2, and 3 of a previous paper,[2] wherein it was pointed out that the same equations were obtained by both the revolving-field and by the cross-field method of analysis.

Values of C_r and C_R have been plotted on Figure 2 to show the range of variation that may be expected in any given motor. These curves show that, for most practical purposes, C_r may be taken as equal to K_r, whereas C_R cannot be neglected, especially if the rotor resistance is even moderately high. Let

$$r_2' = r_2 C_r = \text{apparent secondary resistance} \tag{11}$$

$$X' = XC_R = \text{apparent total reactance} \tag{12}$$

Then equation 2 becomes

$$\dot{Z} = (r_1 + r_2') + jX'$$

It should be noted in passing that Figure 1B also applies to a polyphase induction motor; hence all equations in this appendix apply also to a polyphase induction motor.

Appendix II

Maximum Starting Torque Per Ampere for Split-Phase Motors

Consider point C in Figure 3, which defines the maximum starting torque per ampere. The first problem is to express the line amperes, I_L, in terms of constants already known

$$\overline{OC}^2 = \overline{OF}^2 - \overline{CF}^2 = \overline{OF}^2 - \overline{AF}^2 \tag{14}$$

(Line $\overline{OF}$ is omitted from Figure 3 to avoid confusion.)

But

$$\overline{OF}^2 = \overline{OA}^2 + \overline{AF}^2 + 2\overline{OA}\ \overline{AF}\sin\theta_m \tag{15}$$

Therefore

$$\overline{OC}^2 = \overline{OA}^2 + 2\overline{OA}\ \overline{AF}\sin\theta_m$$

$$= I_m^2 + \frac{2I_m E X_m'}{2X_a' Z_m}$$

$$= I_m^2\left(1+\frac{X_m'}{X_a'}\right) \tag{16}$$

The line current is then

$$I_L = I_m\sqrt{\left(1+\frac{X_m'}{X_a'}\right)} \tag{17}$$

Solving equation 17 for X_a' gives

$$X_a' = \frac{X_m'}{\left(\frac{I_L}{I_m}\right)^2 - 1} \tag{18}$$

But

$$I_L = I_m\sqrt{\frac{(R_m+R_a)^2+(X_m'+X_a')^2}{(R_a^2+X_a'^2)}} \quad \text{[Refer to equation 125]} \tag{19}$$

Eliminating I_L between equations 17 and 19 and solving for R_a gives

$$R_a = \frac{R_m X_a' + Z_m\sqrt{X_a'(X_m'+X_a')}}{X_m'} \tag{20}$$

$$\frac{R_a}{X_a'} = \frac{R_m}{X_m'} + \frac{Z_m}{X_m'}\sqrt{\frac{X_m'+X_a'}{X_a'}} \tag{21}$$

but, from equation 17

$$\sqrt{\frac{X_m'+X_a'}{X_a'}} = I_L/I_m \tag{22}$$

so, equation 21 becomes

$$\frac{R_a}{X_a'} = \frac{R_m + Z_m(I_L/I_m)}{X_m'} \tag{23}$$

or

$$R_a = \frac{X_a'}{X_m'}(R_m + Z_m I_L/I_m) \tag{24}$$

Substituting the value of X_a' in equation 18 for X_a' in equation 24 yields

$$R_a = \frac{R_m + Z_m(I_L/I_m)}{\left(\frac{I_L}{I_m}\right)^2 - 1} \tag{25}$$

Equations 25 and 18 define the resistance and reactance in the auxiliary-winding circuit, which yields a line current of I_L and a maximum-torque-per-ampere winding. These two equations completely define the auxiliary winding. If the reactance of the auxiliary winding is known, equation 20 defines the resistance required and equation 17 the resultant line current.

Appendix III

Starting-Torque Equations for a Capacitor-Start Motor

Conditions for Maximum Starting Torque

Starting conditions for a capacitor-start motor are illustrated in Figure 4. Points C and D represent maximum starting torque per ampere, and maximum starting torque, respectively.

By the geometry of Figure 4

$$\widehat{AD} = \frac{180°+2\theta_m}{2} = 90° + \theta_m$$

$$\widehat{DB} = 180° - \widehat{AD} = 90 - \theta_m \tag{26}$$

or

$$\theta_{ac} = \frac{90-\theta_m}{2}$$

$$\tan(-\theta_{ac}) = \sqrt{\frac{1-\cos(90-\theta_m)}{1+\cos(90-\theta_m)}}$$

$$= \sqrt{\frac{1-\sin\theta_m}{1+\sin\theta_m}} = \sqrt{\frac{Z_m - X_m'}{Z_m + X_m'}}$$

or

$$\frac{-X_{ac}'}{R_{ac}} = \frac{Z_m - X_m'}{R_m} = \frac{R_m}{Z+X_m'}$$

or

$$-X_{ac}' = \frac{R_{ac}}{R_m}(Z_m - X_m') = \frac{R_{ac}R_m}{Z+X_m'} \tag{28}$$

Equation 28 expresses the total net reactance required in the auxiliary phase for maximum starting torque. This equation checks one given by Boothby,[1] if allowance is made for the difference in notation. The quantities given are all algebraic, not vector, quantities.

Conditions for Maximum Starting Torque Per Ampere

Maximum starting torque per ampere is represented by point C in Figure 4. The line current, OC, is expressed by the relationship

$$\overline{OC}^2 = \overline{OF}^2 - \overline{CF}^2 = \overline{OF}^2 - \overline{AF}^2 \tag{29}$$

but

$$\overline{OF}^2 = \overline{OA}^2 + \overline{AF}^2 + 2\overline{OA}\ \overline{AF}\cos\theta_m \tag{30}$$

therefore

$$\overline{OC}^2 = \overline{OA}^2 + 2\overline{OA}\ \overline{AF}\cos\theta_m \tag{31}$$

$$I_L^2 = I_m^2 + \frac{2I_m}{2}\frac{E}{R_{ac}} \times \frac{R_m}{Z_m} \tag{32}$$

$$I_L = I_m\sqrt{\frac{R_{ac}+R_m}{R_{ac}}} \tag{33}$$

or

$$R_{ac} = \frac{R_m}{(I_L/I_m)^2 - 1} \tag{34}$$

This gives an expression for the total resistance in the auxiliary phase. The next step is to find a similar expression for the total reactance in the auxiliary phase. The general expression for line current for a capacitor-start motor is

$$I_L = I_m\frac{\sqrt{(R_m+R_{ac})^2+(X_m'+X_{ac}')^2}}{Z_{ac}}$$

(refer to equation 125) (35)

Eliminating I_L by combining equations 33 and 35, and solving for X_{ac}', one obtains

$$X_{ac}' = \frac{X_m' R_{ac} - Z_m\sqrt{R_{ac}(R_m+R_{ac})}}{R_m} \tag{36}$$

Remembering that

$$X_c = X_{ac}' - X_a' \tag{37}$$

equation 36 can be rewritten

$$X_c = \frac{X_m' R_{ac} - X_a' R_m - Z_m\sqrt{R_{ac}(R_m+R_{ac})}}{R_m} \tag{38}$$

Equation 38 gives the value of external capacitive reactance to be connected in series with the auxiliary winding to obtain maximum starting torque per ampere.

We still have to find X_{ac}' for maximum starting torque per ampere in terms of the line current. Dividing numerator and denominator of the right member of equation 36 by R_{ac}

$$X_{ac}' = \frac{X_m' - Z_m\sqrt{\frac{R_m+R_{ac}}{R_{ac}}}}{R_m/R_{ac}} \tag{39}$$

By use of equation 33, equation 39 reduces to

$$\frac{X_m' - Z_m(I_L/I_m)}{\left(\frac{I_L}{I_m}\right)^2 - 1} \qquad (40)$$

Equations 40 and 34 give the total reactance and total resistance required in the auxiliary phase for a maximum-torque-per-ampere winding having a locked-rotor current of I_L.

Appendix IV

Starting-Torque Equations for a Reactor-Start Motor

The starting conditions of a reactor-start motor are represented by Figure 5. Points C and D represent maximum starting torque per ampere and maximum starting torque, respectively.

MAXIMUM STARTING TORQUE

$$\widehat{AD} = \frac{180° - 2\theta_a}{2} = 90° - \theta_a \qquad (41)$$

$$\theta_{mR} = \angle DAB = \frac{\widehat{BD}}{2} = \frac{90° + \theta_a}{2} \qquad (42)$$

By comparing equation 42 with the derivation of equation 28 in Appendix III, it is seen that

$$X_{mR} = \frac{R_a R_{mR}}{Z_a - X_a'} \quad \text{or} \quad \frac{R_{mR}}{R_a}(Z_a + X_a') \qquad (43)$$

since

$$X_R = X_{mR} - X_m'$$

$$X_R = \frac{R_a R_{mR}}{Z_a - X_a'} - X_m' \text{ or } \frac{R_{mR}}{R_a}(Z_a + X_a') - X_m' \qquad (44)$$

Equation 44 gives the value of external reactance to be inserted in series with the main winding to obtain maximum starting torque.

MAXIMUM STARTING TORQUE PER AMPERE

In Figure 5, wherein point C represents maximum starting torque per ampere,

$$\overline{OC}^2 = \overline{OF}^2 - \overline{CF}^2 = \overline{OF}^2 - \overline{AF}^2 \qquad (45)$$

but

$$\overline{OF}^2 = I_a^2 + \overline{AF}^2 + 2I_a\overline{AF}\cos\theta_a$$

or

$$\overline{OC}^2 = I_a^2 + \frac{2I_a E}{2R_{mR}} \times \frac{R_a}{Z_a} = I_L^2 \qquad (46)$$

or

$$I_L = I_a\sqrt{\frac{R_{mR} + R_a}{R_{mR}}} \qquad (47)$$

The line current, I_L, is also expressed by the relation

$$I_L = I_a \frac{\sqrt{(R_{mR} + R_a)^2 + (X_{mR} + X_a)^2}}{Z_{mR}}$$

[refer to equation 125] (48)

Crossed-Coil Power-Factor Meters

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Synopsis: The fundamental relations governing operation of the crossed-coil type of power-factor meter are derived for the particular measurement applications on single-phase, three-wire two-phase, three-wire three-phase, and four-wire three-phase circuits. Emphasis is placed on the usefulness of a graph of either the equilibrium equation or the torque relation in determining the scale distribution.

DURING the past decade or so, the continued growth and, in recent years, the rapid expansion of distribution systems in industry has made industry more and more conscious of the importance of power factor. Although it is recognized that the electrical industry is gradually abandoning the concept of power factor as an indication of load conditions and is concentrating more on measurement of watts and vars, there still are many applications where the measurement of power factor is essential.

The increased demand for the measurement of power factor on single-phase and polyphase circuits has made it necessary to design instruments with a large number of scale ranges. The range of the scale and the application of the instrument to a specified circuit determines the scale distribution. The factors which control scale distribution can be shown from the fundamental relations. To do this it will be necessary

1. To derive the basic torque and equilibrium equations for the single-phase, three-wire two-phase, three-wire three-phase, and four-wire three-phase power-factor meters.

2. To show how the scale distribution can be determined completely from a graph of either the equilibrium expression or the torque equations.

Examples will be made emphasizing the usefulness of these graphs for the selection of scale ranges for given scale angles of deflection.

It is realized that there are several ways by which power factor can be measured. The company with which the author is associated makes two types of power-factor meters. One uses a polarized Z-shaped vane which operates in a rotating magnetic field, and the other makes use of the principle of the crossed coil. In this article attention will be directed to the fundamentals of the crossed-coil-type power-factor meter.

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Equating the right-hand members of equations 47 and 48 and solving for X_{mR} yields

$$X_{mR} = \frac{X_a' R_{mR} + Z_a\sqrt{R_{mR}(R_a + R_{mR})}}{R_a} \qquad (49)$$

The total external reactance to be connected in series with the main winding to obtain maximum starting torque per ampere is, therefore

$$X_R = \frac{X_a' R_{mR} + Z_a\sqrt{R_{mR}(R_a + R_{mR})}}{R_a} - X_m' \qquad (50)$$

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Figure 1. Type AD-6 power-factor meter

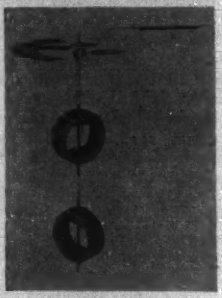


Figure 1a. Moving element of a power-factor meter, showing arrangement of crossed coils

Power-factor meters of the crossed-coil type similar to that shown in Figure 1 are adaptations of the original Tuma phase meter. (See page 546 of reference 1.) The Tuma phase meter as originally developed is a single-phase instrument for measuring the angle between two voltages or a voltage and a current. Although the three-wire three-phase application of the Tuma phase meter is more familiar because of use, it will be well to consider the single-phase application first because of its relative simplicity in analysis by comparison.

Single-Phase Power-Factor Meter: Scale Lag–Lead

The derivation of the fundamental relation is adequately covered in the literature for the single-phase meter. However, it will be advantageous to review this derivation in order to outline the method of attack that will be used in the analysis of the polyphase power-factor-meter applications. Figure 2 is a schematic diagram of the essential elements of a single-phase power-factor meter. Coils A and B compose the moving element. These coils are rigidly coupled to a shaft which is pivoted in an essentially uniform magnetic field produced by field coil F. An inductance in series with coil B and a resistance in series with coil A is connected to the external circuit as shown in the diagram. When current passes through coils F, A, and B, fields will be set up, and coils A and B will each experience turning moments in opposite directions. As A and B are rigidly connected, the moving element will turn to such a position that the resultant moment acting on it will be zero. The deflection D will then be an indication of the power-factor angle or phase angle between the load current and the line voltage.

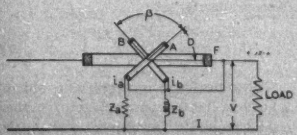


Figure 2. Diagram of a single-phase power-factor meter

Referring to Figure 2, let

D = Angle of deflection as measured between the planes of coils F and A
β = Angle between coils A and B
θ = Power-factor angle or angle between the load current I and the line voltage V
Δ = Angle of lag between current in coil B and voltage V
α = Angle of lag between the current in coil A and voltage V
Z_a, Z_b = Impedances of circuits A and B containing coils A and B, respectively
i_a = Instantaneous current in circuit A
i_b = Instantaneous current in circuit B
i = Instantaneous load current

There will be some mutual inductance between the moving and fixed coils, but in most applications the effect will be negligibly small. In the derivation of the fundamental relations the effect of mutual inductance will be neglected.

If voltage V is taken as the reference vector from which phase differences are measured and the load current I is sinusoidal and is lagging, the instantaneous current values are

$$i = I \sin (\omega t - \theta)$$

$$i_a = \frac{V}{Z_a} \sin (\omega t - \alpha)$$

$$i_b = \frac{V}{Z_b} \sin (\omega t - \Delta)$$

The instantaneous torque acting on coil A will be

$$\tau_a = K_a i_a i \sin D$$

or

$$\tau_a = \frac{K_a I V}{Z_a} \sin D \sin (\omega t - \theta) \sin (\omega t - \alpha)$$

and the average torque over one complete period is

$$T_a = \left[\frac{K_a I V}{Z_a}\right] \sin D \frac{1}{T} \int_0^T \sin (\omega t - \theta) \times \sin (\omega t - \alpha) dt$$

where T is the period and is equal to the reciprocal of the frequency f. Frequency will be assumed constant in the derivation. K_a is a constant involving coil configuration, turns, and so forth.

If the preceding expression is integrated, the final average torque for coil A becomes

$$T_a = 1/2 \left[\frac{K_a I V}{Z_a}\right] \sin D \cos (\theta - \alpha) \qquad (1)$$

Similarly, the instantaneous torque acting on coil B is

$$\tau_b = K_b i_b i \sin (D + \beta)$$

or

$$\tau_b = \left[\frac{K_b I V}{Z_b}\right] \sin (D + \beta) \sin (\omega t - \theta) \times \sin (\omega t - \Delta)$$

and the average torque over a period is

$$T_b = \left[\frac{K_b I V}{Z_b}\right] \sin (D + \beta) \frac{1}{T} \int_0^T \sin (\omega t - \theta) \times \sin (\omega t - \Delta) dt$$

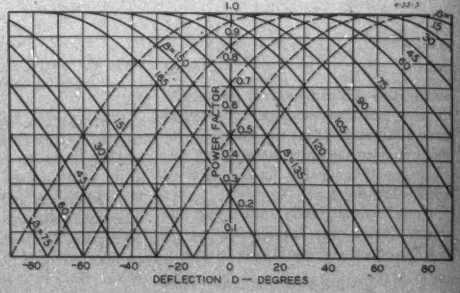


Figure 3. Scale distribution curves of a single-phase power-factor meter for scale lag–lead, plotted from the equilibrium equation

$\beta = \Delta$

—— Curves of β for lagging power factor

– – – Curves of β for leading power factor

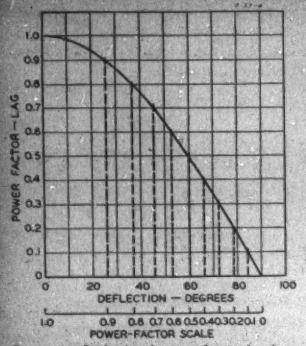


Figure 4. Scale distribution of a single-phase power-factor meter, for condition of $\beta=\Delta=90$ degrees

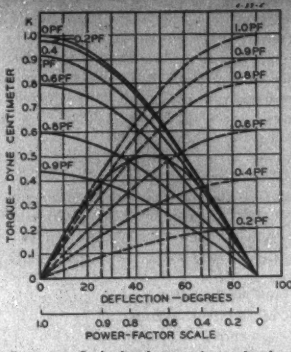


Figure 5. Scale distribution of a single-phase power-factor meter, plotted from the dynamic torque curves

$\beta=\Delta=90$ degrees
---- Coil A
—— Coil B

Therefore

$$T_b=1/2\left[\frac{K_bIV}{Z_b}\right]\sin(D+\beta)\cos(\theta-\Delta) \quad (2)$$

Now for equilibrium the two torques must be equal

$$T_a=T_b \quad (3)$$

or

$$1/2\left[\frac{K_aIV}{Z_a}\right]\sin D\cos(\theta-\alpha) = 1/2\left[\frac{K_bIV}{Z_b}\right]\sin(D+\beta)\cos(\theta-\Delta) \quad (4)$$

The foregoing is the general expression for equilibrium, and if the design of the instrument is such that

$$\frac{K_a}{Z_a}=\frac{K_b}{Z_b} \quad (5)$$

then equation 4 reduces to

$$\sin D\cos(\theta-\alpha)=\sin(D+\beta)\cos(\theta-\Delta) \quad (6)$$

In the ideal instrument $\alpha=0$, $\beta=90$ degrees and $\Delta=90$ degrees. For these conditions equation 6 reduces to

$$\text{Sin } D\cos\theta=\sin(D+90)\cos(\theta-90)$$

or

$$\text{Sin } D\cos\theta=\cos D\sin\theta$$

and

$$\text{Tan } D=\tan\theta$$

from which

$$D=\theta \quad (6a)$$

In practice Δ is never exactly equal to 90 degrees, but Laws on page 548 of reference 1 has shown that the change in deflection from the unity-power-factor reference point is equal to the power-factor angle when $\beta=\Delta$.

If we had originally stated that the power factor was leading instead of lagging, equation 6 would have become

$$\text{Sin } D\cos(\theta-\alpha)=\sin(D+\beta)\cos(\theta+\Delta) \quad (6b)$$

and for the ideal instrument the deflection

$$D=-\theta \quad (6c)$$

Thus we see that for lagging and leading power factors the power-factor angle is equal to plus and minus values of the deflection angle D, respectively.

Assuming in equation 6 that α is negligibly small and solving for D, we find that

$$\text{Cot } D=\frac{1}{\sin\beta(\cos\Delta+\tan\theta\sin\Delta)}-\cot\beta \quad (7)$$

Figure 3 is a plot of function 7 where β has been set equal to all assigned values of Δ. The full lines represent the curves of β for lagging power factor, whereas the dotted lines are the β curves for leading power factor.

If we arbitrarily let the deflection D be positive for lagging power-factor indications and let the instrument pointer be

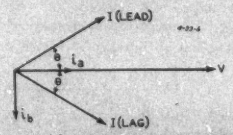


Figure 6. Vector diagram of a single-phase power-factor meter for scale lag–lead

aligned with the A coil, we are in a position to predict from these curves what will happen for any particular value of the angle β between the coils. For instance, if $\beta=90$ degrees and it is desired to have a lag–lead scale with a total scale angle of 90 degrees, the power-factor scale would be approximately 0.7–1.0–0.7. This assumes that at unity power factor the pointer indicates midscale and the deflection D must be ± 45 degrees.

Again suppose $\beta=60$ degrees the scale angle is still 90 degrees and the pointer aligned with coil A. At unity power factor the pointer will indicate 30 degrees from mid scale on the lag side. Consequently, if it was desired to keep the mid-scale point the unity-power-factor point, it would be necessary to advance the pointer 30 degrees on the shaft. In the conventional design of instrument this may not be mechanically feasible, but if it were feasible, the scale distribution would be identical to that obtained for $\beta=90$ degrees. From this family of curves it is evident that if the angle β between the coils is always adjusted so that it equals Δ, the power-factor scales will have identical distributions.

Figure 4 shows the normal distribution of an instrument for the condition where $\beta=\Delta=90$ degrees. One obtains this distribution by projecting the power-factor points from the curve to the abscissa and labeling such points in terms of power factor instead of deflection. The resulting distribution constitutes the power-factor scale.

The scale distribution can also be determined completely from a plot of the dynamic torque curves of each moving coil. If the torque expressions 1 and 2

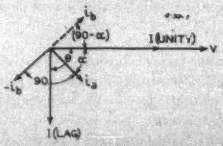


Figure 7. Vector diagram of a single-phase power-factor meter for scale all lag

for coils A and B are plotted, for values of power factor, the points of intersection of corresponding torque curves will form a locus of points of equilibrium. The points on this locus when projected to the abscissa will uniquely determine the scale distribution.

The dynamic torque curves are also valuable in that they describe how torque varies with angular deflection for each coil. Figure 5 shows a graph of these torque curves where for simplicity we have arbitrarily set

$$K=1/2\left[\frac{K_aIV}{Z_a}\right]=1/2\left[\frac{K_bIV}{Z_b}\right] \quad (8)$$

Theoretically it is possible to obtain a scale of 0–1.0–0 power factor, but this would require an instrument scale angle of 180 degrees. In the types AD–6 and 7 power-factor meters, the maximum

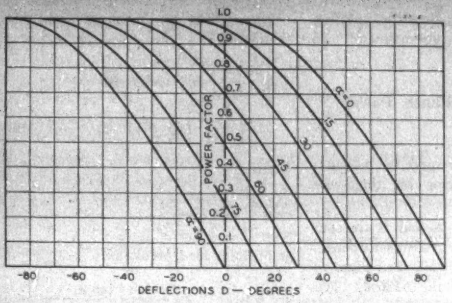


Figure 8. Scale distribution curves of a single-phase power-factor meter for scale all lag, plotted from the equilibrium equation

$\beta = 90$ degrees

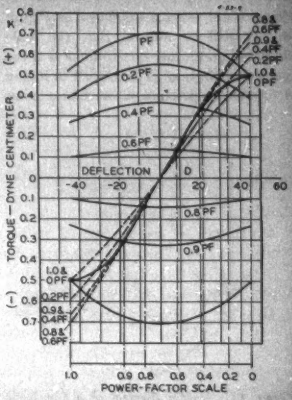


Figure 9. Scale distribution of a single-phase power-factor meter with scale all lag, determined from the dynamic torque curves

$\alpha = 45$ degrees
$\beta = 90$ degrees
--- Coil A
—— Coil B

scale for lag and lead is 0.5–1.0–0.5 power factor. This is obtained with $\beta = \Delta = 90$ degrees and the pointer aligned with coil A.

Occasionally it is required to produce a scale all lag or all lead. In the foregoing analysis we have seen that theoretically it is possible to obtain a scale all lag or all lead by mechanically shifting the pointer with respect to coils A and B. Mechanical design may make it virtually impossible to obtain the proper pointer-coil relation to give a scale all lag or lead. Consequently, it becomes necessary to make certain changes in the electrical constants. The method for doing this is discussed in the following section.

Single-Phase Power-Factor Meter: Scale All Lag

In the following analysis let us assume a condition in which the scale is all lag, that is, unity power factor is at the right end of the scale and zero power factor at the left end. This analysis can also apply to any such scale range as 0.3 to 0.8 power-factor lag. To do this and still keep the same mechanical arrangement of coils and pointer as in the previous section it is necessary to shift electrically the 90-degree relation of the potential circuits such that the instrument indication will fall within the prescribed scale angle.

In the standard lag–lead instrument of the previous section the current i_a in circuit A is in phase with the applied voltage and i_b is 90 degrees lagging this voltage. Vectorially, the voltage V and i_a bisects the angle of the lead and lag load-current vectors which represent the extremes of the power-factor scale range. Figure 6 shows this vector relation. If the scale is to be all lag, then the current i_a must be made to lag V by some angle α such that the current vector i_a will approximately bisect the angle enclosed by the load-current vectors representing the ends of the power-factor scale. Current i_b must also lag V by $(\alpha + 90)$. To obtain the proper lag relation between i_b and V capacitance and resistance are placed in series with coil B. Current i_a will now lead V by $(90 - \alpha)$ but can be made to lag by reversing the connections. Figure 7 shows the new vector relations. By referring to the vector diagram in Figure 7 the instantaneous current values can now be determined and the torque expressions derived. The instantaneous currents are

$$i = I \sin (\omega t - \theta)$$

$$i_a = \frac{V}{\sqrt{R_a^2 + L_a^2\omega^2}} \sin (\omega t - \alpha)$$

$$i_b = \frac{V}{\sqrt{R_b^2 + 1/C_b^2\omega^2}} \sin [\omega t + (90 - \alpha)]$$

Following the previous procedure the torque on coil A is

$$T_a = \left[\frac{K_a I V}{\sqrt{R_a^2 + L_a^2\omega^2}}\right] \sin D \frac{1}{T} \times \int_0^T \sin (\omega t - \theta) \sin (\omega t - \alpha) dt$$

which upon integration yields

$$T_a = 1/2 \left[\frac{K_a I V}{\sqrt{R_a^2 + L_a^2\omega^2}}\right] \times \sin D \cos (\theta - \alpha) \quad (9)$$

and the torque on coil B is

$$T_b = \left[\frac{K_b I V}{\sqrt{R_b^2 + 1/C_b^2\omega^2}}\right] \sin (D + \beta) \frac{1}{T} \times \int_0^T \sin (\omega t - \theta) \sin [\omega t + (90 - \alpha)] dt$$

or

$$T_b = 1/2 \left[\frac{K_b I V}{\sqrt{R_b^2 + 1/C_b^2\omega^2}}\right] \times \sin (D + \beta) \sin (\theta - \alpha) \quad (10)$$

For equilibrium

$T_a = T_b$

When

$$\frac{K_a}{\sqrt{R_a^2 + L_a^2\omega^2}} = \frac{K_b}{\sqrt{R_b^2 + 1/C_b^2\omega^2}}$$

the equilibrium equation becomes

$$\sin D \cos (\theta - \alpha) = \sin (D + \beta) \sin (\theta - \alpha) \quad (11)$$

For the case when $\beta = 90$, expression 11 becomes

$$\sin D \cos (\theta - \alpha) = \cos D \sin (\theta - \alpha)$$

or

$$\tan D = \tan (\theta - \alpha)$$

from whence

$$D = \theta - \alpha \quad (11a)$$

The deflection is now equal to the difference between θ and α and not equal to θ as previously. However α is a constant, and the deflection D is proportional to θ. If equation 11 is solved for D

$$\cot D = \frac{\cot (\theta - \alpha)}{\sin \beta} - \cot \beta \quad (12)$$

The plot of this expression for $\beta = 90$

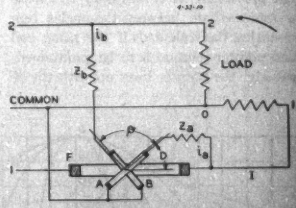


Figure 10. Diagram of a three-wire two-phase power-factor meter

degrees and varying α is shown on Figure 8. It will be noticed that the scale distribution for any one value of α is the same distribution as developed in Figure 4 for the single-phase power-factor meter

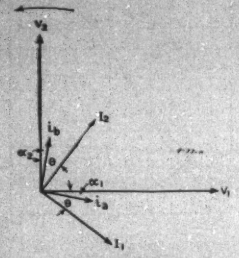


Figure 11. Vector diagram of a three-wire two-phase power-factor meter

with scale lag–lead. In fact, expression 12 for $\alpha=0$ and $\beta=90$ reduces to expression 7 for $\beta=\Delta=90$. From this we could have predicted the distribution would be the same.

The torque curves of each element depicted in Figure 9 are radically different from those in Figure 4, but the resultant scale distribution is the same. Although angle α was arbitrarily set equal to 45 degrees for these torque curves, other values of α would give similar scale distributions. The essential difference for other values of α would be revealed in different values of the angle of deflection.

By referring again to Figure 8 it will be noted that if it is required to have a scale 0.3 to 0.8 power factor or the current lags the voltage by 72.5 and 37 degrees, respectively, α should be chosen to be approximately 60 degrees. As pointed out previously, it is necessary to choose α intermediate between the angles representing the scale ends if the same coil and pointer relation is to be maintained, namely, the pointer lines up with the A coil. If this is done, then the resulting scale angle will be approximately 38 degrees.

Three-Wire Two-Phase Power-Factor Meter

Some applications require the measurement of power factor on three-wire two-phase circuits.

In Figure 10 coils A and B are connected in series with resistors to phases 1 and 2, respectively, while their common lead is connected to the neutral. The same notation shall be used as previously with the exception that α_1 and α_2 are the angles of lag between the currents in circuits A and B and the load voltage. These lagging currents are due to the inductive effect of the movable coils.

With reference to Figure 11 which is the vector diagram for a balanced inductive load the instantaneous current values for lagging power factor are

$$i = I \sin (wt-\theta)$$

$$i_a = \frac{V}{Z_a} \sin (wt-\alpha_1)$$

$$i_b = \frac{V}{Z_b} \sin (wt+[90-\alpha_2])$$

The coil torques are now

$$T_a = \left[\frac{K_a IV}{Z_a}\right] \sin D \frac{1}{T} \int_0^T \sin(wt-\theta) \times \sin (wt-\alpha_1)dt$$

$$T_a = 1/2\left[\frac{K_a IV}{Z_a}\right] \sin D \cos (\theta-\alpha_1) \quad (13)$$

$$T_b = \left[\frac{K_b IV}{Z_b}\right] \sin (D+\beta) \frac{1}{T} \times \int_0^T \sin (wt-\theta) \sin [wt+(90-\alpha_2)]dt$$

$$T_b = 1/2\left[\frac{K_b IV}{Z_b}\right] \sin (D+\beta) \sin (\theta-\alpha_2) \quad (14)$$

For equilibrium T_a must equal T_b; therefore

$$1/2\left[\frac{K_a IV}{Z_a}\right] \sin D \cos (\theta-\alpha_1) = 1/2\left[\frac{K_b IV}{Z_b}\right] \sin (D+\beta) \sin (\theta-\alpha_2) \quad (15)$$

Letting

$$K_1 = \frac{K_a}{Z_a} \text{ and } K_2 = \frac{K_b}{Z_b}$$

and solving for D results in

$$\text{Cot } D = \frac{K_1}{K_2}\left[\frac{1+\tan\theta \tan\alpha_1}{\sin\beta\left(\tan\theta\dfrac{\cos\alpha_2}{\cos\alpha_1} - \dfrac{\sin\alpha_2}{\cos\alpha_1}\right)}\right] - \cot\beta \quad (16)$$

If design is such that $K_1=K_2$ then $\alpha_1=\alpha_2=\alpha$ and equation 16 reduces to

$$\text{Cot } D = \frac{\cot(\theta-\alpha)}{\sin\beta} - \cot\beta \quad (17)$$

This relation is identical to equation 12 for the single-phase power-factor meter

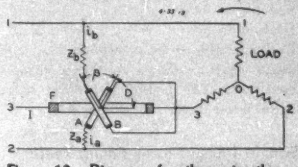


Figure 13. Diagram of a three-wire three-phase power-factor meter

with scale all lag. However, in general α in equation 17 is small and can be neglected. If this is done, the deflection then reduces to

$$\text{Cot } D = \frac{\cot\theta}{\sin\beta} - \cot\beta \quad (18)$$

The graph of this expression will give the same scale distribution as the single-phase power-factor meter for $\beta=90$ degrees. Equation 7 is identical to equation 18 for $\Delta=90$ degrees. The essential difference between the operation of a power-factor meter on three-wire two-phase and a single-phase meter with scale lag–lead is that in the three-wire two-phase application the 90-degree relation is obtained by the 90-degree displacement between phase voltages, whereas in the single-phase meter it is necessary to lag the current in one circuit by the use of a series reactor.

If expression 18 is plotted for lag and lead power factors with varying β, a family of distribution curves will result as shown on Figure 12. Each value of β

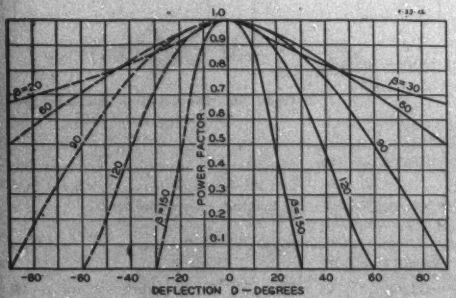


Figure 12. Scale distribution curves for a three-wire two-phase power-factor meter, plotted from the equilibrium equation

—— β curves for lagging power factor
– – – β curves for leading power factor

will give a different scale distribution. The curve that will give the same scale distribution as the single-phase application is the one for which $\beta = 90$ degrees.

It can be seen from Figure 12 that for a given scale angle of 90 degrees with, for example, $\beta = 60$ degrees that the maximum power-factor scale that can be obtained for a scale all lag or all lead would be 0.5 to 1.0 power factor. Also, for a

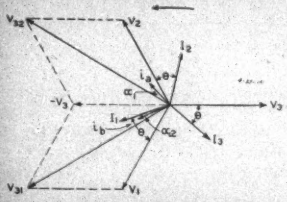


Figure 14. Vector diagram of a three-wire three-phase power-factor meter

scale having both lag and lead with the same scale angle, the maximum range would be approximately 0.8 lag to 0.8 lead.

It will not be necessary to plot the dynamic torque curves as the curves of Figure 5 with the resulting scale distribution apply to the three-wire two-phase power-factor meter for $\beta = 90$ degrees.

Three-Wire Three-Phase Power-Factor Meter

Figure 13 shows the connection of a power-factor meter on a three-wire three-phase balanced inductive load. Again use is made of the phase relation between voltages to obtain the desired condition for power-factor measurement. The only mechanical difference between the three-wire two-phase and three-wire three-phase power-factor meter is the setting of the coil angle β and pointer location. Although the mechanical difference is slight, the torque and distribution characteristics are radically different between the two instruments.

In reference to the vector diagram in Figure 14 the instantaneous current values are

$$i_a = I_a \sin(\omega t - \theta) = I \sin(\omega t - \theta)$$

for balanced currents

$$i_a = \frac{V_{32}}{Z_a} \sin[\omega t + (150 - \alpha_1)]$$

$$i_b = \frac{V_{31}}{Z_b} \sin[\omega t - (150 + \alpha_2)]$$

where α_1 = lag angle between i_a and V_{32} and α_2 = lag angle between i_b and V_{31}. It will be noted that for stability of instrument operation it is necessary to reverse line voltage V_{13}.

For balanced inductive loads the coil average torques are

$$T_a = 1/4\left[\frac{K_a I V}{Z_a}\right] \sin D[-\sin(\theta - \alpha_1) - \sqrt{3}\cos(\theta - \alpha_1)] \quad (19)$$

$$T_b = 1/4\left[\frac{K_b I V}{Z_b}\right] \sin(D + \beta)[\sin(\theta - \alpha_2) - \sqrt{3}\cos(\theta - \alpha_2)] \quad (20)$$

For equilibrium $T_a = T_b$. Setting $T_a = T_b$ and solving for the deflection D, we have

$$\text{Cot } D = \frac{K_1}{K_2}\left[\frac{1 - \tan\theta\cot\alpha_1 - \dfrac{\sqrt{3}\tan\theta - \sqrt{3}\cot\alpha_1}{\sin\beta\left(\tan\theta\dfrac{\cos\alpha_2}{\sin\alpha_1} - \dfrac{\sin\alpha_2}{\sin\alpha_1} - \sqrt{3}\dfrac{\cos\alpha_2}{\sin\alpha_1} - \sqrt{3}\tan\theta\dfrac{\sin\alpha_2}{\sin\alpha_1}\right)}}{\cot\beta}\right] \quad (21)$$

where

$$K_1 = \frac{K_a}{Z_a}, \text{ and } K_2 = \frac{K_b}{Z_b}$$

If design is such that

$$K_1 = K_2$$

then

$$\alpha_1 = \alpha_2 = \alpha$$

and equation 21 reduces to

$$\text{Cot } D = \frac{\tan\alpha(1 - \sqrt{3}\tan\theta) - (\tan\theta + \sqrt{3})}{\sin\beta[(\tan\theta - \sqrt{3}) - \tan\alpha(1 + \sqrt{3}\tan\theta)]\cot\beta} \quad (22)$$

In most cases α is small, and

$$\text{Cot } D = -\left[\frac{\tan\theta + \sqrt{3}}{\sin\beta(\tan\theta - \sqrt{3})} + \cot\beta\right] \quad (23)$$

When the power factor becomes zero, equation 23 is indeterminate but can be evaluated. For power factor = 0

$$\text{Cot } D = -\left[\frac{1 + \cos\beta}{\sin\beta}\right] \quad (24)$$

The family of curves resulting from equation 23 are shown in Figure 15. Each curve will give one particular scale distribution. For any given scale angle one can determine from these curves the power-factor scale range for any coil angle β.

Expression 23 was derived for the condition of lagging power factor. For leading power factor the relation for the deflection becomes

$$\cot D = \frac{\tan\theta - \sqrt{3}}{\sin\beta(\tan\theta + \sqrt{3})} + \cot\beta \quad (23a)$$

This expression when plotted will give the same scale distribution as equation 23, but the angles of deflection D will have different values. However, for an instrument whose pointer is set to bisect the angle β between coils, the scale distributon will be symmetrical about the unity-power-factor point for lag and lead conditions with any given value of β.

The value of β most commonly used is the one for which $\beta = 75$ degrees. This angle is selected because the resulting scale distribution more nearly approaches linearity than any other value of β.

If the curve for $\beta = 75$ degrees is separately plotted as on Figure 16, the scale distribution is more clearly determined. It will be noted from this distribution that if the scale is to be lag–lead for a scale angle of 90 degrees, the maximum power-

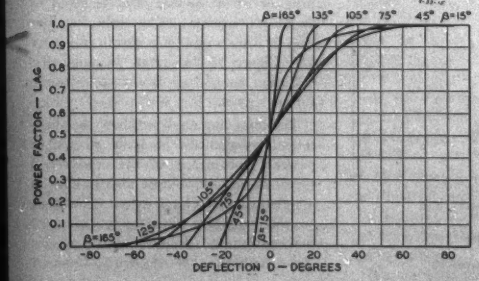


Figure 15. Scale distribution curves for a three-wire three-phase power-factor meter, plotted from the equilibrium equation

$\alpha = 0$

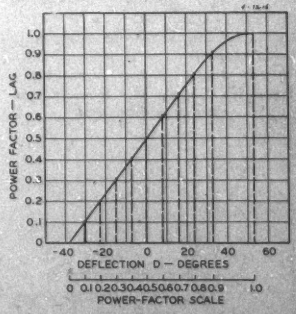


Figure 16. Scale distribution of a three-wire three-phase power-factor meter for $\beta = 75$ degrees

$\alpha = 0$

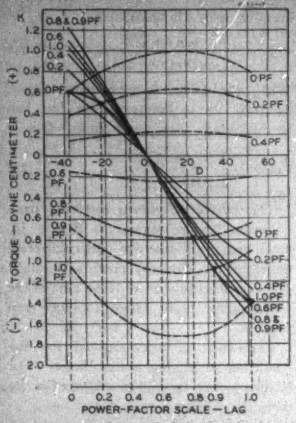


Figure 17. Scale distribution of a three-wire three-phase power-factor meter, plotted from the dynamic torque curves

$\alpha = 0$ —— Coil *A*
$\beta = 75$ degrees - - - Coil *B*

factor range will be approximately 0.6 lag to 0.6 lead.

Figure 17 is a plot of the dynamic torque curves which also show the resulting scale distribution. Barring inaccuracies in graphing, the distribution in Figure 17 and Figure 16 are identical.

Four-Wire Three-Phase Power-Factor Meter

The last application that shall be discussed in this article is the condition for four-wire three-phase power-factor measurement. In this case phase-to-neutral voltages are used instead of phase-to-phase voltages as in the three-wire three-phase application. Angle β is then selected to give the best scale distribution for the particular scale range desired.

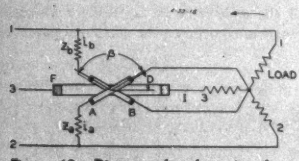


Figure 18. Diagram of a four-wire three-phase power-factor meter

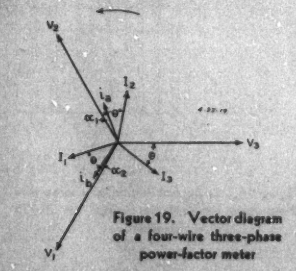
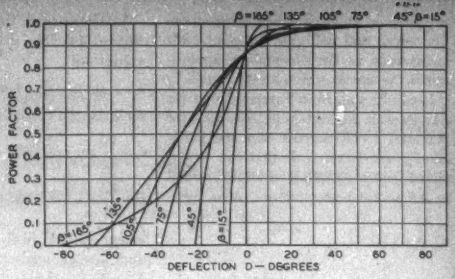


Figure 19. Vector diagram of a four-wire three-phase power-factor meter

Figure 20. Scale distribution curves of a four-wire three-phase power-factor meter, plotted from the equilibrium equation

$\alpha = 0$



With reference to Figure 19, which is the vector diagram of the instrument connections schematically shown in Figure 18, the instantaneous currents for a balanced inductive load using V_3 as the reference vector are

$$i_a = I_3 \sin(wt-\theta) = I \sin(wt-\theta)$$

$$i_a = \frac{V_2}{Z_a} \sin(wt+120-\alpha_1)$$

$$i_b = \frac{V_1}{Z_b} \sin(wt-120-\alpha_2)$$

The average coil torques turn out to be

$$T_a = 1/4\left[\frac{K_a I V}{Z_a}\right] \sin D\,[-\sqrt{3}\times \sin(\theta-\alpha_1) - \cos(\theta-\alpha_1)] \quad (25)$$

and

$$T_b = 1/4\left[\frac{K_b I V}{Z_b}\right] \sin(D+\beta)\,[\sqrt{3}\times \sin(\theta-\alpha_2) - \cos(\theta-\alpha_2)] \quad (26)$$

For

$$K_1 = \frac{K_a}{Z_a} \text{ and } K_2 = \frac{K_b}{Z_b}$$

the expression for the deflection at equilibrium is

$$\text{Cot } D = \frac{K_1}{K_2}\left[\frac{\sqrt{3} - \sqrt{3}\tan\theta\cot\alpha_1 - \tan\theta - \cot\alpha_1}{\sin\beta\left(\sqrt{3}\tan\theta\dfrac{\cos\alpha_2}{\sin\alpha_1} - \sqrt{3}\dfrac{\sin\alpha_2}{\sin\alpha_1} - \dfrac{\cos\alpha_2}{\sin\alpha_1} - \tan\theta\dfrac{\sin\alpha_2}{\sin\alpha_1}\right)} - \cot\beta\right] \quad (27)$$

When the design is such that

$K_1 = K_2$, and $\alpha_1 = \alpha_2 = \alpha$

then equation 27 reduces to

$$\text{Cot } D = \frac{\tan\alpha(\sqrt{3} - \tan\theta) - (\sqrt{3}\tan\theta + 1)}{\sin\beta[(\sqrt{3}\tan\theta - 1) - \tan\alpha(\sqrt{3} + \tan\theta)]} - \cot\beta \quad (28)$$

For $\alpha = 0$, which is a practical assumption

$$\text{cot } D = -\left[\frac{\sqrt{3}\tan\theta + 1}{\sin\beta(\sqrt{3}\tan\theta - 1)} + \cot\beta\right] \quad (29)$$

By direct comparison of equation 29 with 23 the similarity that exists will be observed. The only difference is in the location of the $\sqrt{3}$ term. This slight difference, however, makes quite a difference in the scale distribution and torque curves. For the condition when the power factor is zero the evaluated indeterminate form of equation 29 reduces to the same expression as equation 24.

The analysis of the four-wire three-phase application is quite similar to the three-wire three-phase case. For this reason details have been omitted. Expression 29 has been derived for the condition of lagging power factor, but a similar expression for leading power factor would give the same scale distribution.

From Figure 20 one can see that it is possible for a 100-degree scale to obtain a scale range of 0.9–1.0–0.9 power factor if β is set equal to approximately 75 degrees. The most common condition in practice for a lag-lead scale is for β to equal 105 degrees. The scale distribution for this condition is shown in Figure 21. Figure 22 also gives the same distribution as plotted from the dynamic torque curves.

The foregoing analyses show the theoretical possibilities of scale ranges in power-factor meters of the crossed-coil type. A variety of scale distributions is inherent and to a large extent dependent on the particular circuit application of the instrument. Limitations on ranges and distribution are necessarily imposed

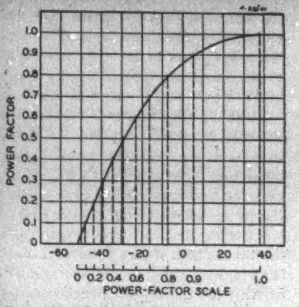


Figure 21. Scale distribution of a four-wire three-phase power-factor meter for $\beta=105$ degrees

$\alpha=0$

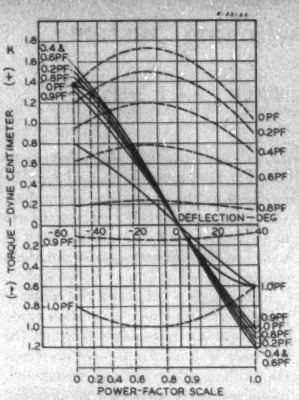


Figure 22. Scale distribution of a four-wire three-phase power-factor meter, plotted from the dynamic torque curves

$\alpha=0$
$\beta=105$ degrees
—— Coil A
--- Coil B

because of mechanical design; however, the derived distribution curves for each application should prove of value as an aid in selecting proper power-factor scale ranges for given scale angles of deflection.

Power Factor of Unbalanced Polyphase Circuits

In the previous summary of polyphase power-factor meters, emphasis was placed on the application to systems having symmetrical sets of voltages and currents or balanced loads. Although it is beyond the scope of this article to analyze mathematically the effect of system unbalance on the measurement of power factor on polyphase circuits, it might be well to consider briefly this question. It is conceivable that, for a given condition of unbalance, the torque equations of a polyphase power-factor meter could be derived, and an expression for the instrument indication obtained. This indication may or may not be an indication of the power factor of the system. The question immediately raised is: "What is the meaning of power factor in a polyphase circuit?" In the past there has been some disagreement as to what power factor is in a polyphase circuit and only recently has any definition been recorded. "The American Standard Definition of Electrical Terms" gives several definitions of power factor. To quote from this publication, they are

"Power factor is the ratio of active power to apparent power. The power factor A is given by the equation

$A=P/U$

[where P = active power and U = apparent power]. It follows that the power factor of a polyphase circuit must be designated as arithmetic or algebraic to indicate whether arithmetic or algebraic apparent power is used in the denominator. If both the currents and potential differences are sinusoidal and if both form symmetrical sets, then

$A=\cos(\beta-\alpha)$

"Vector power factor is the ratio of the active power to the vector power... If both the currents and potential differences are sinusoidal and if both form symmetrical sets, then the vector power factor is the same as the power factor."

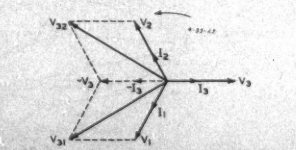


Figure 23. Vector diagram of a three-wire three-phase balanced resistance load $I_1=I_2=I_3=I$

These definitions clearly suggest that three different power factors can be realized which are determined by the use of arithmetic or algebraic apparent power or vector power. For balanced systems the three power factors are equal for all angular displacements between phase voltages and currents. In the unbalanced system the three power factors are equal only when all phase currents are inphase with their respective phase voltages and are different for other angular displacements. Unity power factor is a term that is commonly used to denote the condition when a current and a voltage are inphase.

For an example of the effect of unbalance on instrument indication let us take a simple extreme case. Suppose that the three-wire three-phase instrument shown in Figure 13 is connected to a balanced pure resistance load. As unity power factor, previously defined, exists in this system, let us further assume that the instrument is calibrated to indicate this unity power factor. Now let us unbalance the load by opening the connection to the load at two, thereby making the current in this phase equal to zero. Also let the three line voltages remain a symmetrical set and the instrument potential circuits be excited. For this extreme condition of unbalance the current vector I, which originally was inphase with phase voltage V_3, will now have shifted 30 degrees leading V_3 since it will be inphase with line voltage V_{31}. Although unity power factor still exists for the unbalanced condition, the instrument no longer indicates unity power factor but is in error by 30 electrical degrees. Vector diagrams shown in Figures 23 and 24 will serve to clarify these two conditions.

One can see that it is possible to have several combinations of system unbalance that might conceivably produce the same instrument indication. If this is true, then any given instrument indication would tell the observer nothing concerning the condition of circuit unbalance that produced that indication. Conversely, as previously pointed out, for a given unbalance an instrument indication might be obtained by means of a mathematical derivation that would tie up the indication with a particular unbalance condition, but what would be the practical value of this since the condition of system unbalance is already known?

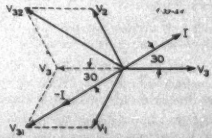


Figure 24. Vector diagram of a three-wire three-phase resistance load–balanced voltages $I_3=0$, $I_1=I_2=I$

For the standard adopted application of power-factor indicators on polyphase circuits it is reasonable to assert that, unless the polyphase system is balanced, the power-factor-meter indication is without significance.

Reference

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Crossbar Toll Switching System

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IN AUGUST of 1943 a new mechanical toll switching system was placed in service in Philadelphia. It was designed by engineers of the Bell Telephone Laboratories and of the department of operation and engineering of the American Telephone and Telegraph Company for large toll centers, particularly those where most of the offices are of the panel and crossbar types. The Philadelphia installation was planned before the war. Even then it was apparent that a mechanical switching system was needed urgently to secure faster and more economical switching. War conditions produced an abnormal growth in toll traffic that accentuated the need for the new equipment. The system was therefore installed as rapidly as the heavy load of war work on the engineering and manufacturing organizations of the Bell System would permit. It is now contributing materially to the war effort by providing adequate switching facilities for the increased volume of traffic.

This new toll switching system includes the following important features:

1. Crossbar switching equipment with senders and markers.

2. Operator dialing or pulsing over toll lines to panel and crossbar areas.

3. A cordless switchboard for handling traffic which cannot be dialed or pulsed through the system by distant operators.

4. A new rapid method of transmitting switching codes known as a-c key pulsing.

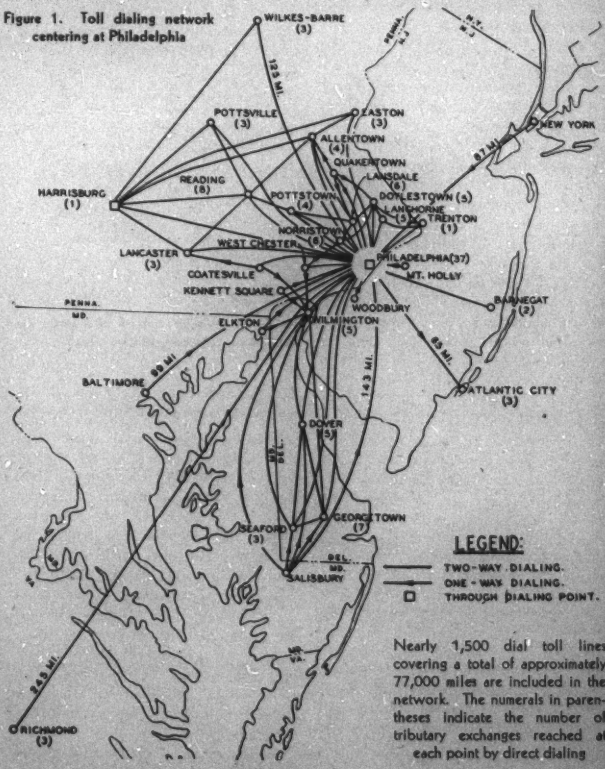
5. Four-wire switching, that is, the provision of separate conductors for voice transmission in each direction.

The function of toll switching equipment is to provide connections that will enable subscribers to converse with other subscribers in localities too distant to be reached over their own local network. If the toll areas in which the calling and called subscribers are located have a sufficient community of interest, there may be direct circuits between them, and at each terminal there will be a switched connection to a local office. Where the call involves two toll offices having no direct circuits between them, it must be routed through one or more intermediate toll offices, and switching connections will be required at each intermediate point as well as at the originating and terminating offices.

In the past it has been the ordinary practice to have every connection made by an operator who inserts plugs on the two ends of a cord into jacks on which the toll lines and trunks are terminated. In recent years an improved practice, known as toll-line dialing, has been applied in a few of the smaller toll areas where step-by-step switching equipment is used in the local offices. With this method, the outward toll operator who accepts the subscriber's call plugs into a toll line, and then by means of a dial temporarily associated with her cord sends dial pulses to direct the movement of switches in the distant toll office to select a trunk to the called subscriber's local office. She continues by dialing the subscriber's listed number to drive switches in the local office to establish a connection. The subscriber's bell is then rung automatically by the local circuit. If intermediate switching is involved, the operator also dials the connection through the intermediate office. Thus the manual labor of establishing connections at intermediate and inward toll switchboards is eliminated, the outward operator's work-time is reduced since she does not have to pass orders for connections and wait for them to be established, and the subscriber receives faster service.

In the toll dialing operation just described, the switching equipment in toll and local offices is all of the step-by-step variety, the movement of switches being under control of impulses dialed on a decimal basis. In areas where the local

Figure 1. Toll dialing network centering at Philadelphia



Nearly 1,500 dial toll lines covering a total of approximately 77,000 miles are included in the network. The numerals in parentheses indicate the number of tributary exchanges reached at each point by direct dialing

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switching equipment is of the panel and crossbar types, on the other hand, the action of switches is controlled by senders, with the aid of decoders or markers. The new toll switching equipment permits the introduction of toll-line-dialing operation in such areas as well. The term "toll-line dialing" is of generic character and includes not only the use of actual dials by operators but also the use of keysets and senders that generate signals of a different nature. The extent to which toll-line dialing is used in the Philadelphia area is shown in Figure 1.

There are, of course, many toll-line groups in the Philadelphia toll office not shown in Figure 1. These are groups that at present cannot economically be arranged for toll-line dialing. Cordless toll positions are provided as part of the new toll switching system to provide for handling calls over these other groups until such time as they can be arranged for toll-line dialing. They are equipped with keysets to direct the establishment of connections for the manual groups of lines just as connections for the dial groups are controlled by dials or keysets at distant positions.

Basic Arrangement

The crossbar switch used in the new toll switching system is shown in Figure 2. Since it has been described in detail by Scudder and Reynolds,[1] it will be sufficient to describe it as a co-ordinate arrangement of contacts giving ten lines on one ordinate access to ten or 20 on the other.

All toll lines and trunks are terminated on crossbar switches, and their interconnection is accomplished by senders, controllers, and markers with their connecting equipment. These units are common either to the entire office or to a substantial portion of it. The circuits comprising the common equipment are relatively complex and expensive, and are held only for the brief periods required for establishing connections. The information needed by the common equipment to guide it in setting up a connection is supplied in the form of a numerical code, usually of three digits, by an operator either in the same office with the equipment or in a distant office. The code is received by an incoming sender, which forwards it to a marker. The marker, by means of temporary connecting equipment, attaches itself to the switches on which the two circuits to be connected are located and establishes a connection between them. The relation of the common equipment to the toll lines, trunks, and switches is indicated by the schematic diagram in Figure 3.

Figure 2. A 10 by 20 crossbar switch

Operating Methods

The manner in which calls through the toll crossbar system are handled from the operator's viewpoint may be demonstrated by use of a few examples.

Outward Calls

Assume a subscriber in Philadelphia is calling a subscriber in Harrisburg whose number is 6-5432. The Philadelphia end of the connection is illustrated diagrammatically by Figure 4.

The outward operator at a switchboard of the familiar cord type will select an idle trunk to the toll crossbar office and will then dial or key the code 321, which represents Harrisburg, followed by the called subscriber's number, 6-5432. The crossbar equipment will use the three code digits, 321, to select an idle toll line and will then transmit the remaining digits over the toll line to drive switches to the called subscriber's line. The subscriber's bell will be rung automatically, and, when the subscriber answers, the lighted cord lamp in front of the outward operator will be extinguished. On station-to-station calls, the operator then starts timing the conversation for charge purposes. At the end of conversation both cord lamps will light to indicate the hang-up of calling and called subscribers, and the operator will pull down her cords. This will release the entire connection.

Now assume an outward call to a Chicago subscriber. The Philadelphia–Chicago group operates on a ring-down basis, and the outward operator, after selecting the tandem trunk, will dial or key only the three-digit code representing the Chicago group. The crossbar equipment will make the connection to an idle Chicago toll line and cause ringing current to be sent over the line. This will light a lamp associated with the toll line in Chicago, where an operator will answer the call. The outward operator in Philadelphia, will pass the order to the Chicago operator, who will complete the call. The outward operator must remain on the connection until the called subscriber answers, in order to start timing, because supervisory signals to indicate the called subscriber's answer and hang-up are not returned over a ringdown line. At the end of conversation she will pull down her cords when the calling subscriber hangs up. This will release the connection through the switches to the Chicago toll line. The inward operator at Chicago

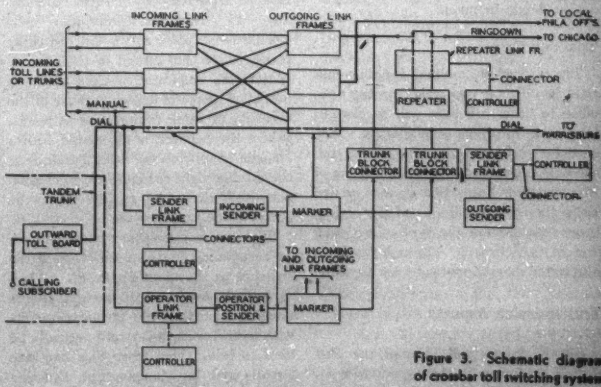

Figure 3. Schematic diagram of crossbar toll switching system

will release her connection upon receipt of a lighted cord lamp indicating that the called subscriber has hung up.

Inward Calls

An inward call over a dial toll line, illustrated by Figure 5, requires no operator in the crossbar toll area. Assume the call is to the Philadelphia number Market 1234. The distant operator will key or dial MAR-1234. The crossbar equipment will use the MAR (627) to select an idle trunk to the Market local office and the remaining digits to drive switches in that office to the called subscriber's line. The connection will be released at the end of conversation when the distant operator releases her connection.

An inward call over a ring-down toll line is represented by Figure 6. In response to ringing current on the toll line, a cordless position will be connected automatically to the line. An operator at the position will receive the order for Market 1234 and will key the complete number—MAR-1234—on her keyset, causing the connection to be established as described. Her position is then released from the connection. Since the ring-down line can give no indication at the inward end that it has been released at the outward end, the toll crossbar equipment must recognize the called subscriber's hang-up in order to release the connection. This is done by equipment in the relay circuit associated with the incoming toll line, which times for two seconds after he hangs up, and, if he has not again removed his receiver from the switchhook, releases the connection. If the called subscriber flashes, if his line is busy, if he fails to answer, or if the outward operator rings on the toll line, an inward operator (not necessarily the one who originally handled the call) is again connected to the line, and lamps on her position indicate what action should be taken.

Through Calls

The method of handling incoming calls that are to be switched through the office to other toll lines will be obvious from the foregoing explanation. The need for an operator in the crossbar toll office is determined only by the nature of the incoming line. She is not needed when the incoming line is of the dialing type, regardless of the type of outgoing line to be selected. Through traffic is illustrated diagrammatically by Figure 7.

Transmission Aspects

All the longer toll lines of the Bell System are four-wire, that is, opposite directions of transmission are over separate paths, each with one-way amplifiers at suitable intervals. These two paths are combined by means of a hybrid coil into a single two-wire circuit before reaching the telephone at each end.

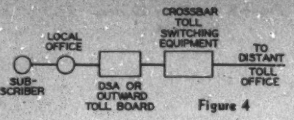

Figure 4

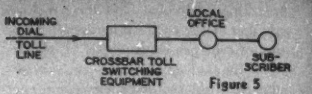

Figure 5

At switching offices in this country, all four-wire circuits have been previously reduced to two-wire by a hybrid coil before they reach the switching point and thus have been switched as two-wire circuits. This is indicated in Figure 8a which shows a four-wire toll line at the left switched to a two-wire toll line with a terminal repeater. There are limits to the transmission efficiency of such arrangements, since the two-wire junction permits speech currents traveling in one direction to be reflected partially toward the talker at the hybrid coil, thus causing echoes. When there are two-wire junctions at both ends of the circuits, there is a closed path around which "singing" may result. In addition, when cord circuit repeaters are added at a two-wire switching point there is a two-wire junction on each side of the repeater, and more echoes result—being made greater by the gain of the repeater. A similar result is obtained at a "switching-pad" office when gain is effectively inserted by removing two-wire switching pads instead of by adding a repeater. Since any circuit in the office must be capable of connection to any one of a large number of other circuits, which may not all have the same characteristics, the balancing network at the junction obviously cannot be made to balance accurately all of them individually. As a result, a "compromise" network is employed. A two-wire switching point, where cord circuit or terminal repeaters are employed, is thus always a potential source of echoes because of the necessity of using compromise networks. Where the network is associated with a single circuit, on the other hand, as at the extreme right of Figure 8a, a precision network is used which greatly reduces the echo volume.

With the new crossbar system all lines are terminated on a four-wire basis at the switches as shown in Figure 8b. When these lines are four-wire circuits, this is done by omitting the terminating sets with hybrid coils that would normally be used to bring them down to a two-wire circuit, and by changing the signaling means, switching pads, operators' connections, and other circuit elements to a four-wire basis. On the two-wire toll lines with terminal repeaters the same general result is obtained by removing the hybrid coil on the office side of the repeaters. On two-wire toll lines without terminal repeaters, a hybrid coil is added with one two-wire branch toward the two-wire line and the other toward the balancing network, and with the four-wire branches connecting to the switches. The net result is the same as the two-wire repeatered toll line in Figure 8b with the two amplifiers and switching pads removed.

When two four-wire or two-wire toll lines with terminal-repeaters are switched together on a four-wire basis, all sources of echo in the switching office are eliminated. Some echo is of course returned from the hybrid coil connecting the two-wire repeater to the two-wire line, but this can be kept small by keeping the balancing between the precision network and its associated line high.

If the two-wire toll line of Figure 8b did not have terminal repeaters or switching pads, the switching pads in the four-wire toll line would be removed, thus effectively inserting gain in the over-all connection. Because of the high balance at the two-wire hybrid coil, considerable gain may be inserted in this manner, thus allowing greater loss in the nonrepeatered two-wire circuit. This greater loss permits saving in copper and loading and frequently permits omitting a terminal two-wire repeater that would be required with a two-wire switching system.

With four-wire switching, therefore, certain of the two-wire lines, chiefly those that are not used as intermediate links in long built-up circuits, may be made of the high-loss type. If two of these high-loss lines are to be connected together directly, there may be too much over-all loss from subscriber to subscriber. To avoid this, repeaters are switched in, thus reducing the over-all loss. There are no objectionable effects because of echoes or singing because at the point where these repeaters are inserted the circuit is four-wire, and thus there are no hybrid coils to act as a source of additional echoes. The hybrid coils, where the four-wire circuit is connected to the outgoing two-wire line, are precision networks, and even with the additional gain the echoes do not become objectionable, the two-wire

balances with precision networks inserting loss in the echo returned toward the subscriber. The insertion of repeaters is done automatically depending upon markings associated with the two lines connected.

These high-loss two-wire lines may be lines to other toll offices or connecting trunks to local offices. The determination of which trunk should be high loss and which low loss depends upon the economy which may be obtained in outside plant and terminal repeaters compared to the cost of providing additional gain when it is required.

Switching pads are provided on four-wire toll lines and on two-wire toll lines with terminal repeaters to permit the loss to be adjusted for the different types of connections that may be involved. With two-wire switching, special hybrid coil arrangements and means for inserting or removing switching pads were necessary to permit satisfactory talking in both directions on four-wire circuits.

Potentially, four-wire switching offers considerable promise. The percentage of four-wire toll lines will increase in the future both because long circuits tend to increase at a greater rate than do shorter circuits and because the general use of carrier throughout the toll plant will tend to reduce the minimum lengths of four-wire toll lines which are economical. With four-wire circuits and four-wire switching in general use, many improvements in echo suppression and volume control would become possible and economical.

Progress of Calls Through the System

The manner in which a connection is established through the crossbar equipment may be demonstrated by pointing out the function of each item of equipment in Figure 3 as the call progresses. For this purpose it is not necessary to know the composition of the individual parts, which will be described later.

The crossbar switches on which the incoming trunks and toll lines are terminated are assembled in groups called incoming link frames, and those on which the outgoing trunks and toll lines are terminated are called outgoing link frames. These two types of link frames are interconnected so that any incoming trunk or toll line may be connected to any outgoing trunk or toll line.

Dial or Key-Pulsing Call

The example previously used of the subscriber in Philadelphia who has originated a toll call to Harrisburg 6-5432 may again be employed. The outward operator selects a "tandem" trunk connecting to the crossbar toll switching equipment. Relays associated with this tandem trunk in the crossbar system signal the sender link frame that an incoming sender is required. A controller circuit then becomes attached to the sender link frame and connects the tandem trunk through the frame to an incoming sender. The operator then keys or dials the code 321, which is assigned to the Harrisburg toll-line group. She also keys the called number 6-5432, and these digits as well as the code digits are recorded by the sender. The sender in turn obtains access to a marker and transmits the Harrisburg code to it. This code is registered and translated by the marker which causes a route relay in the marker to operate. This relay directs the marker to the proper trunk-block connector where the test leads for all the toll lines to Harrisburg are located. Upon gaining access to the connector, the marker selects an idle toll line and immediately makes that line appear busy to other calls.

To connect the tandem trunk to the selected Harrisburg toll line, the marker must identify the incoming and outgoing link frames on which these are located. The signal identifying the outgoing link frame is furnished to the marker over a lead from the outgoing toll line through the trunk-block connector, while the incoming link frame is identified by a signal which the marker receives from the tandem trunk over one of the leads through the sender link frame, and the sender.

The marker then gains access to the incoming and outgoing link frames involved and excludes all other markers from these frames. It then selects an idle path through these frames and operates the proper magnets of the crossbar switches to establish the connection. After this the marker releases and disconnects itself from the incoming and outgoing link frames as well as from the sender and the trunk-block connector. The total time required for the marker to perform all its functions is about one second.

When the toll line to Harrisburg has been selected, an outgoing sender will become associated with it through a sender link frame under the direction of a controller. The incoming sender will then transfer the called number to the outgoing sender, and that sender will control the switching equipment at Harrisburg through which the call is completed. Upon completion of their functions, the incoming and outgoing senders are dismissed.

Ring-Down Call

When, as in the case of the call to Chicago, the outgoing toll line is arranged for ring-down operation, the outgoing sender is not used. The operator will key only the code number of the toll-line group. This is sufficient to cause the call to be routed to the Chicago toll line as described for the previous call. A ringing signal is then transmitted by relay equipment associated with the toll line to signal the Chicago operator.

Calls Requiring Operator Assistance

Incoming calls from ring-down toll lines require operator assistance at the crossbar toll office as previously mentioned. An incoming signal from such a toll line causes the line to be connected through an operator link frame to an operator position. This position is of the cordless type and is equipped only with keys and lamps. The operator is automatically connected to the toll line and receives the necessary details of the incoming call from the outward operator. She then operates keys which cause the called number to be registered in a sender associated with the position. This sender is then associated with a marker, and the call is completed in the manner previously described.

In general, the operator at the crossbar toll office is released from the call as soon as the positional sender has completed its functions. If the call is not completed, as when the called subscriber's line is busy, an operator is reconnected to the call, and the status of the call is indicated by lamp signals at the position. The operator then makes the proper oral report to the calling operator. If the crossbar toll operator is required to take further immediate action on a call, the operator may remain associated with the

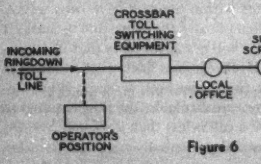

Figure 6

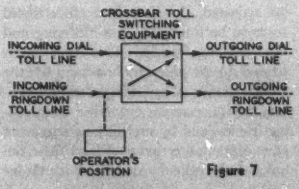

Figure 7

call even after the called number has been registered in the positional sender. This is accomplished automatically under conditions always requiring this association, or the operator may operate a key to retain association with the call.

Through Call Requiring a Switched-in Repeater

If an incoming call from either a dial or ring-down toll line is switched to another toll line of either variety and both lines are high loss, a switched-in repeater is required. The marker is told by a d-c potential on a lead of the incoming line that it is high loss and by a contact of the route relay associated with the outgoing toll-line group that the outgoing line is high loss. Under these conditions, as soon as the marker has established the connection, it will send a signal to the outgoing line which will cause it to call for a repeater. A controller will thereupon be attached to the repeater link frame on which the outgoing line appears and will insert a repeater in the connection. The marker and controller are released as soon as their functions are completed, and the repeater remains connected for the duration of the call.

Principal Elements of the System

1. Incoming and Outgoing Link Frames

A "frame" is an assembly of switches interconnected as an electrical unit to serve a group of either incoming or outgoing lines. The incoming and outgoing link frames are composed of a primary and a secondary bay of switches, each ten switches high, with as many supplementary bays as are required to accommodate the number of trunks necessary to make efficient use of the call-carrying capacity of the frame. Incoming trunks appear on the primary and supplementary primary bays of the incoming frames, and outgoing trunks appear on secondary and supplementary secondary bays of outgoing frames. Each bay has a capacity of 100 trunks. The links connecting the primary and secondary bays are called *A* links, those connecting the secondary bays of the incoming frames and the primary bays of the outgoing frames are called *B* links or junctors, and those connecting the primary and secondary bays of the outgoing frames are called *C* links. Each incoming frame has connections to all outgoing frames but none to other incoming frames, and the reverse is true of outgoing frames. A simplified schematic diagram of the arrangement is indicated in Figure 9.

It will be noticed that *A* and *C* links interconnect switches on a frame, while *B* links interconnect frames. The pattern of *A* and *C* links is fixed, and there are always 200 on a frame in ten groups of 20 each, so that each trunk has access to 20 *A* or *C* links. While the distribution of *B* links follows an orderly pattern, it will vary with the number of frames, which is, of course, dependent upon the size of the office.

There are always at least 20 *B* links from each incoming frame to each outgoing frame and therefore 20 paths by which an incoming trunk can reach a particular outgoing trunk. Each path consists of three links in series, and between any one incoming and any one outgoing line, a particular *A* link can be used with only one particular *B* and *C* link, and thus, if one is busy, the entire path is unavailable for use on the call. The method of selection employed by the markers is such that the lowest numbered path, all elements of which are idle, is used. This is the simplest method and has the additional advantage of giving a lower probability of blocking a call because of inability to match links than would a random choice of links.

Since there are only 200 *B* links per frame and 20 links to each opposing frame

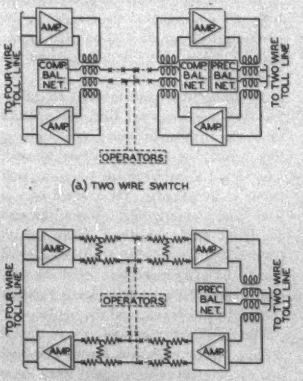

Figure 8. Typical transmission paths through switching offices

are required, the size of an office would seem to be limited to ten incoming and ten outgoing frames. This limit is extended to 20 of each, however, by the simple device of providing a supplementary bay of secondary switches on incoming frames, and by multiplying *B* links on pairs of frames so that each may share the links of the other. An office with 20 incoming frames and 20 outgoing frames is comparable in size to a 10,000-line local crossbar office.

In the Philadelphia installation it was found desirable to provide two separate trains of switches, one for outward and through traffic, the other for inward traffic. The system is described in this paper, however, as a single train system, since all that is required for a clear understanding of its operation may be presented on that basis.

2. Operator Link Frames

As shown in Figure 3, an operator link frame is used to connect incoming manual trunks to operators' positions. It is composed of 100-point (ten by ten) crossbar switches in primary-secondary alignment and accommodates 100 trunks on the primary side and 40 cordless positions on the secondary side. Each group of ten trunks is served by four links, each of which gives access to ten positions. Figure 10 depicts half an operator link frame, the other half being an exact duplicate of it with the trunks multiplied to both halves.

The establishment of connections through operator link frames is directed by a group of controllers in much the same manner as the markers direct connections through incoming and outgoing frames. The controllers gain access to trunks, links, and positions through controller connectors consisting of multicontact relays.

To obtain substantially uniform treatment of calls and particularly to guard against "orphan calls," the "gate" principle of serving them is employed. When a controller is attached to a link frame, it scans the ten subgroups of trunks and admits within the gate all which have at least one waiting call. Those which have no waiting call will be locked outside, and calls which may subsequently arrive on them will not be served until the frame has been released and has secured a new controller. The controller then selects one of the admitted subgroups and locks out the individual trunks of that subgroup which do not have waiting calls. Having served all accepted waiting calls in that subgroup, it proceeds to the next subgroup, treats it in the same manner, and so continues until all subgroups admitted within the gate have been served. It then releases the frame and so marks it that it will not again serve that frame until all other frames having calls waiting at that time have been served. When operators are available, the time required to serve a call is less than a second.

Several precautions are taken to insure

even distribution of the load to operators:

(*a*). A standard pattern for cabling positions to link frames has been carefully constructed with that end in view.

(*b*). Half of the controllers test for idle positions in one direction, the other half in the opposite direction.

(*c*). The position appearances on the frames are divided into small groups, and a controller starts testing with a different group on each call until a complete cycle has been made.

3. Sender Link Frames

Sender link frames are similar to operator link frames and are used to give access to both incoming and outgoing senders. Two-way dial toll lines appear only on incoming sender link frames and obtain access to both types of senders through them, a portion of the outgoing senders being multipled to some incoming sender link frames for that purpose. The connections through sender link frames are directed by controllers in the manner described for operator link frames.

4. Repeater Link Frames

Repeater link frames are similar in construction and operation to operator and sender link frames but provide 60 links giving access to 60 repeaters to serve 100 outgoing toll lines. The greater link capacity is required because the repeaters are held for the duration of the conversation.

5. Cordless Switchboard Positions

The switchboard positions are of the cordless type, all functions performed by the operator being effected by key operations. The physical appearance of the switchboard is shown in Figure 11.

Calls reach a position through three channels known as loops, and it is the loops which appear on the operator link frames. Triplicate channels are provided to permit calls which require continuing attention by the operator to be held on the position and to permit overlap operation, that is, the admission of a new call to a position before complete disposition has been made of a previous call. Each loop appears on the position as a key and three associated lamps. Normally calls are connected to the operator's telephone circuit automatically, but, when a loop is held to her position, she may connect her telephone circuit to it at will, and the key is provided for this purpose. The lamps are:

(*a*). A guard lamp which flashes when the loop is connected to the operator's telephone circuit.

(*b*). A busy lamp which is lighted steadily as long as the loop is held to a trunk through the link frame.

(*c*). A supervisory lamp which follows signals received from the called trunk.

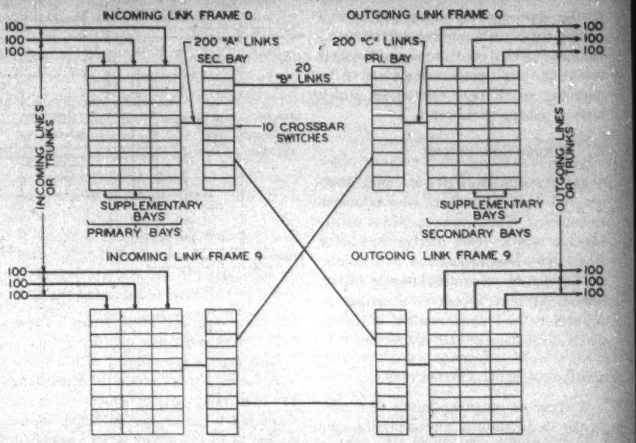

Figure 9. Links between incoming and outgoing trunks

A complete sender is associated with each position and appears on the marker connector frame for connection with the marker. To permit overlap operation, however, the sender is actually divided into two parts, that part concerned with the code digits being associated with the operator's telephone circuit and the remaining part functioning independently as a normal incoming sender. The two parts may be simultaneously connected to two different trunks through two of the position loops.

The keyset used by the operator in pulsing consists of 11 strips of ten-button keys and a start key. The setting of the first three strips is transferred to the marker for selection of the called trunk, and that of the remaining strips is transmitted to an outgoing sender, or to a sender in a distant office if the outgoing trunk is to an office equipped to receive a-c key pulses.

A number of lamps and keys common to the position are provided to apprise the operator of the proper course of action to be followed and to enable her to take the necessary action to meet the various conditions which are presented to her.

6. Senders

The function of a sender is to accept incoming pulses, interpret them, register them as numerical digits, and transmit them forward for the purpose of controlling switching operations. The wide variety of trunks which must be interconnected by this system has made it advisable to provide separate incoming and outgoing senders, and to transfer to the outgoing senders those digits which must be used to control switching operations in distant offices. Although this method of operation results in several types of senders in the office, each sender is less complicated, since it may be arranged for only the kind of pulsing required by the trunks with which it is associated. Outgoing trunks arranged for a-c key pulsing do not require an outgoing sender, the pulses being sent from the incoming sender directly to a receiving sender in the distant office.

There are two groups of incoming senders, one arranged to receive dial pulses, the other to receive a-c or d-c key pulses. Both are arranged to transmit either d-c pulses to an outgoing sender in the same office or a-c key pulses to a sender in a distant office. D-c key pulsing represents digits by combinations of high and low conditions of two polarities of battery over two wires and ground and is limited to use between items of equipment in the same building. A-c key pulsing employs combinations of frequencies in the voice range, and may be used for any distance. The key-pulsing senders are signaled by a d-c potential on a lead of the incoming trunk whether to prepare for reception of a-c or d-c pulses.

There are also two groups of outgoing senders, one arranged to transmit either the type of pulses required by the equipment in local panel offices or the type used to reach manual offices in a panel area, the other to transmit either dial pulses

of the type used to drive step-by-step equipment or call announcer pronouncements to manual offices equipped for their reception. A d-c potential on a lead of the outgoing trunk tells the sender which kind of pulsing to transmit.

7. Marker Connectors

Marker connectors give incoming senders and cordless position senders access to markers. They are composed of multicontact relays. One marker connector frame gives 18 senders access to all markers through two separate channels. Each sender, therefore, appears twice on marker connectors and each marker as many times as there are marker connectors.

8. Trunk-Block Connectors

A group of outgoing trunks to a particular destination is spread evenly over outgoing frames. To enable the marker to test the desired group and select an idle trunk, however, it is necessary to assemble test leads representing the group at some point. The sleeve and select magnet leads of all trunks are brought to the trunk-block connector for this purpose.

A single connector accommodates 400 trunks with duplicate appearances and gives all markers access to them. A block consisting of 40 trunks may be a complete trunk group so far as destination is concerned, only part of a group, or several groups.

The select magnet lead which is brought through the trunk-block connector carries information to the marker identifying the location of the trunk on the outgoing frame. Since it is frequently necessary to make temporary reassignments of toll lines, the trunk-block connector is supplemented by assignment patching jacks through which the sleeve and select magnet leads of many toll lines are carried.

9. Markers

The several hundred relays comprising the marker, which is the "brains" of the system, form a number of related but somewhat independent groups with different duties to perform. Only the more important of these will be discussed.

One group of relays checks the integrity of the leads between the incoming sender and the marker. A second group registers the three digits comprising the code for the outgoing trunk group. A third group, part of which are of the multicontact class, serves to convert the three-digit registration into the marking of a single terminal which may be cross-connected to a route relay representing a particular outgoing trunk group. These route relays constitute another group.

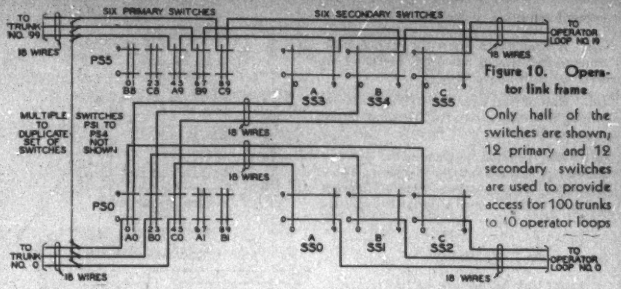

Figure 10. Operator link frame

Only half of the switches are shown; 12 primary and 12 secondary switches are used to provide access for 100 trunks to 10 operator loops

Each marker is equipped with a route relay for each trunk group to be reached. The route relay carries contacts which are connected to punchings providing information as to the nature of its associated trunk group and the means of locating it. Some punchings guide the marker to the selection of the trunk block on which the group appears and tell it where to begin and end testing of the trunks in the block. Others tell it whether the trunks are of a variety requiring the insertion of voice repeaters on some connections and supply information to control the action of incoming senders and cordless positions.

In another group 40 relays are simultaneously connected to the sleeve leads of the trunks through the trunk block in order to select an idle trunk in the desired group. Another group of relays tests *A*, *B*, and *C* links, matching them for an idle path through the switches of the incoming and outgoing frames. A chain of 20 pairs of multiwound relays is used for this purpose. In setting up a connection, an *A*, a *B*, and a *C* link in series form one channel, and a set of this sort is connected to three of the windings of each pair of test relays. If any winding is energized, the associated channel is unavailable for use on the connection. The first pair of relays in the chain remaining unoperated selects the channel to be used.

A set of vacuum tubes and filters is used for frame identification, that is, for determining on which frames the two trunks to be interconnected are located. This information is presented to the marker in the form of three frequencies imposed on the select magnet leads of the trunks. The frequencies used are the odd harmonics of 85 cycles from 425 cycles to 1,615 cycles.

A-C Key Pulsing

One of the interesting new features of this switching system is the use of a-c key pulsing to transmit digits over toll lines. Exchange names and subscribers numbers have previously been transmitted by d-c key pulsing within an office, but this is not practicable for transmission over long toll circuits. A-c key-pulsing signals, however, can go wherever the speech currents can go and at the same speed, so there is no limit on the range of this method.

When an operator uses a suitable key-set or when the sender recognizes by suitable marking that the circuit over which it is to send a number is equipped for a-c key pulsing, a *KP* signal is sent out which consists of 1,100 cycles and 1,700 cycles, simultaneously. At the distant end, the reception of the two frequencies makes the a-c key pulsing receiver sensitive to further signals. The numbers or letters are then sent one at a time, each represented by two of the frequencies 700, 900, 1,100, 1,300, and 1,500 cycles. Finally, a signal consisting of 1,500 and 1,700 cycles simultaneously is sent to indicate the end of the number and to make the receiver insensitive again. The receiving sender then proceeds to set up the call.

The receiver is insensitive to other currents such as noise or speech, except during the interval while the signals are being sent. To avoid a false *KP* signal and to protect against wrong numbers during the sensitive interval, the receiver is arranged so that two and only two frequencies can indicate a number. If the proper signals are not received, supervisory signals are sent back to notify the operator originating the call by a flashing light that she must put the call through again.

By a-c key pulsing, it is possible to transmit numbers over any satisfactory telephone circuit faster than any operator can send them. An incoming dial sender of the new system, for example, receives numbers from an operator at the calling end of the trunk at the rate of about one digit per second, while it will send numbers over the outgoing trunk at the rate of ten digits per second. The

use of pulsing also gives a one-way check of the transmission continuity of the toll line.

Facilities for Handling Delayed Traffic

The cost of long-distance circuits has to date rendered it imperative to engineer them on a delay basis in order to maintain toll service at a reasonable cost to the subscriber. This means that in the busy hours, calls will frequently encounter "no-circuit" conditions. Under such conditions it becomes desirable to relieve operators of the burden of making repeated unsuccessful attempts to secure a circuit. This purpose is accomplished by means of overflow circuits.

An overflow-control circuit is associated with each toll-line group appearing on outgoing frames and permits a maximum of from one to four simultaneous connections to it depending on the size of its associated toll-line group. The trunk circuits affording entrance to the overflow-control circuit appear on the trunk-block relay along with the associated toll lines. A call for a group having all circuits busy is connected to over flow. As long as all circuits are busy, the overflow circuit returns a slow flash to all incoming circuits connected to it, and, when a circuit becomes available, a fast reorder flash is returned. If all circuits of a group are busy and all of its associated overflow trunks are also busy, the call will be routed to one of a group of master busy trunks common to the office. Master busy trunks return a distinctive irregular flash.

The flashes are returned to the originating operator on calls employing dial toll lines or tandem trunks. On calls coming in over ringdown toll lines, the cordless operator is held if the connection is routed to overflow. She is given a lighted overflow pilot lamp, and the loop is automatically locked to her position so that she may subsequently take action when a circuit becomes available.

Occasionally in normal times, very heavy overloads of traffic on some groups occur because of holiday demands or unpredictable catastrophes. Under war conditions these overloads occur rather frequently. When they occur, calls tend to accumulate in quantities which will tax the capacity of an affected trunk group for extended intervals.

Under these conditions, facilities are required to enable the operating force to serve calls as nearly as practicable in order of their filing time. For this purpose, a manual call-order board is provided. This board is similar to other cord switchboards except that twin plugs and jacks are used so that through calls may be established on a four-wire basis. The call-order operator establishes a through connection by first plugging one end of a cord into a tandem trunk and keying over it to secure the toll line, then repeating the operation with the other end of the cord to secure the other toll line. Her position is equipped with a ten-button keyset. Whenever circuit groups become so congested that calls cannot be served within five or ten minutes, call orders for through calls are assembled at the call-order board.

When congestion develops to the point where delay must be quoted, a patch is made from the overflow-control circuit to a delay-quoting trunk appearing in the call-order switchboard. As long as connections are in overflow, a call-order operator will repeatedly quote the delay indicated by the trunk. When the patch has been made, all operators except those at the call-order board are denied access to the group. The outward operators in the same toll-center area must then leave requests with the call-order operators to secure circuits for them.

Maintenance Facilities

Perhaps the most interesting of the maintenance facilities is the marker trouble indicator. When a marker encounters trouble in the process of setting up a connection, it calls in the trouble indicator and leaves a record of the trouble. The record is displayed on lamps which indicate how far the marker had progressed with the call, what individual equipment items had been involved, and, where possible, the nature of the trouble encountered.

A similar trouble indicator on a smaller scale is provided for controllers. Automatic routine testing equipment for senders and outgoing trunks is also provided.

The new toll testboard associated with the system carries twin-jack appearances of toll lines to permit four-wire switching. It is also equipped with dialing and key-pulsing apparatus to enable it to operate with the mechanical equipment.

Traffic Meters

A comprehensive set of measuring apparatus is provided to keep the supervisory force informed as to the performance of the office. This equipment, consisting of ampere-hour meters, ammeters, recording ammeters, message registers, and lamps records traffic load carried by various elements of switching equipment, delayed calls, and other items of interest to the office management and to the traffic engineer.

Conclusion

The new switching system offers many improvements over the switching equipment which has been in use in the large toll centers in the past.

Transmission objectives are met with greater ease, and substantial economies are made in the outside plant and in repeater equipment.

It provides facilities which enable outward toll operators to direct the establishment of connections without the aid of inward or through operators. This results in operating economies and improved service to the subscriber. The provision of a cordless switchboard to handle traffic which must remain for some time on a ring-down basis enables that traffic also to be handled more expeditiously and with operating economies.

The use of senders and markers for controlling the establishment of connections will undoubtedly play an increasingly important part in future long-distance switching, since these devices permit more complete mechanization of the long distance operating job. The switching system which has been described is, therefore, inherently well adapted to meet the future requirements of the continually improving long-distance-switching network now functioning in the United States.

Figure 11. Cordless switchboard

Reference

1. Crossbar Dial Telephone Switching System, F. J. Scudder, J. N. Reynolds. AIEE Transactions, volume 58, 1939, May section, pages 179–92.

Regulation of A-C Generators With Suddenly Applied Loads

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DETERMINATION of the voltage drop at the terminals of small generators during the starting of relatively large motors has long been an important problem, particularly in connection with the starting of large motors on power-house auxiliary generators. Interest in this problem has been greatly accentuated by the wartime application of many small a-c generators, in fixed and mobile locations, supplying motors of ratings amounting to an appreciable fraction of the generator rating. It is essential in such applications to be able to predict accurately the maximum voltage drop in order to be sure that motor starters on the line will not drop out and that motors already running will not stall when large additional loads are started. Other types of apparatus are critical to low voltages of short duration, particularly if such low voltages recur frequently.

A practical method[1] has been available for some time for determining generator voltage–time curves following the sudden application of load. In this method the voltage–time curve is constructed by a step-by-step graphical process. In this paper equations are derived that yield directly the minimum voltage of the voltage–time curve. The calculation of a large number of specific cases using both these methods has indicated that many of the factors that enter theoretically into the problem have practically a small effect on voltage drop, and that by using average or typical values for the factors of small importance, the maximum voltage drop during motor starting can be expressed in curves in terms of only a few important parameters.

A general study has been made to determine the effects of varying independently all of the factors entering into the regulation problem. This study demonstrates conclusively that average values can be used for the less important factors. As a result it has been possible to present sets of curves that show with accuracy the maximum voltage drop to be expected when motors of any size are started on generators of various characteristics. These curves can be used without involved calculation and with a knowledge of only the most essential factors entering into the problem; namely, the full voltage inrush current of the motor, the transient reactance and the open-circuit time constant of the generator, and the response of the exciter. Tables are included to show the average values of these various constants for generators and exciters commonly used; therefore, a fairly good approximation to the maximum drop can be obtained from the information given in the paper without detailed information regarding the equipment involved.

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Development of the mathematical method for the determination of maximum voltage drops is abstracted from a thesis, "Suddenly Applied Loads on Generators With Quick-Response Excitation," by R. C. Cheek, submitted to the University of Pittsburgh in partial fulfillment of the requirements for the degree of master of science.

Curves of Maximum Voltage Drop

The final results of the studies described in this paper are the maximum-voltage-drop curves, Figure 1, for suddenly applied low-power-factor load. The curves apply to a regulating system having essentially the elements shown in Figure 2. A direct-acting regulator varies resistance in the field of a self-excited exciter to regulate the a-c generator voltage. This system of regulation is the one most commonly used with a-c generators ranging in size from the smallest up to machines of several thousand kilovolt-amperes. While the curves were calculated for machines having self-excited exciters, they apply approximately in the case of large machines having separately excited exciters.

Figure 3 is a typical curve of the voltage–time behavior of a generator under suddenly applied load. The calculated points of this figure were obtained by means of equations derived in a later section of this paper. When a low-power-factor load is suddenly thrown on a generator, the terminal voltage drops suddenly as shown in Figure 3 because of internal reactance drop and then begins a gradual drop to a much lower value because of armature reaction. The initial drop initiates action of the voltage regulator, which removes resistance from the exciter field. This causes the exciter voltage to begin building up, stopping the downward trend of generator voltage and bringing this voltage back to normal. The most important single feature of this "voltage-dip" characteristic is the maximum drop reached. Entire dips involve times of 0.5 to 1.5 seconds, and the voltage is near its minimum value for several cycles. Consequently, the maximum drop, reached at the low point of a dip, is the criterion of undesired starter dropout, motor stalling, and other phenomena associated with low voltage. It is this maximum drop that has been plotted in the curves of Figure 1.

The curves of Figure 1 show the maximum voltage drop as a function of the amount of low-power-factor load added directly at the generator terminals for a wide range of values of generator transient reactance. Families of curves of this type are given for various generator time constants and exciter responses. Table I shows probable minimum, maximum, and average values of the generator reactances affecting voltage drop. Figure 4 shows typical time constants of machines of different sizes and speeds.

A summary of the basis for the curves of Figure 1 is given in Table II. Although derived on the basis of no initial load, the curves apply well for the mixed static and rotating initial loads usually encountered. The curves were calculated under the assumption of 35 per cent power factor for the applied load. This is a typical starting power factor for squirrel-cage induction motors, and as shown in a later section wide variations in power factor from this typical figure will have little effect on the maximum drop.

In the determination of maximum voltage drops from Figure 1, applied loads should be expressed in terms of per cent generator current at full voltage. In the calculation of the curves the added load was treated as a fixed impedance. The impedance of a normal induction motor is fairly constant at the locked-rotor figure at speeds up to at least 75 per cent of full speed, and a loaded induction motor will not normally reach this speed during the short time required for the regulator to stop the downward trend of generator voltage; therefore, in determining maximum drops from Figure 1, induction motors can be assumed without signifi-

cant error to be fixed impedances during the starting period.

Example: Suppose a 50-horsepower 440-volt induction motor, having 600 per cent starting current at full voltage, is to be started across the line on a 500-kva generator of 30 per cent transient reactance. Full-load kilovolt-ampere input for a typical motor of this size is 48.2 kva. The full-voltage starting inrush is therefore 6×48.2=290 kva or 58 per cent of generator rating. With a generator time constant of 2.0 seconds and an exciter response of 3.0 or higher, the maximum drop according to Figure 1 is 17.5 per cent, or in other words the minimum voltage is 82.5 per cent. This provides considerable margin above contactor-dropout voltages of 65 to 70 per cent and the 70 per cent voltage at which a fully loaded motor of 200 per cent pull-out torque would stall if it were already running on a line supplied by the generator.

Factors Influencing Voltage Regulation

The maximum voltage drops have been given as functions of four principal parameters; namely, added load, generator transient reactance, generator time constant, and exciter response. There are a number of other factors entering into the equations for maximum voltage drop, but as will be shown these are generally minor factors, which can justifiably be represented by average values in determining voltage drops.

In this section all of the various factors that affect the terminal voltage of a generator during the starting of a large

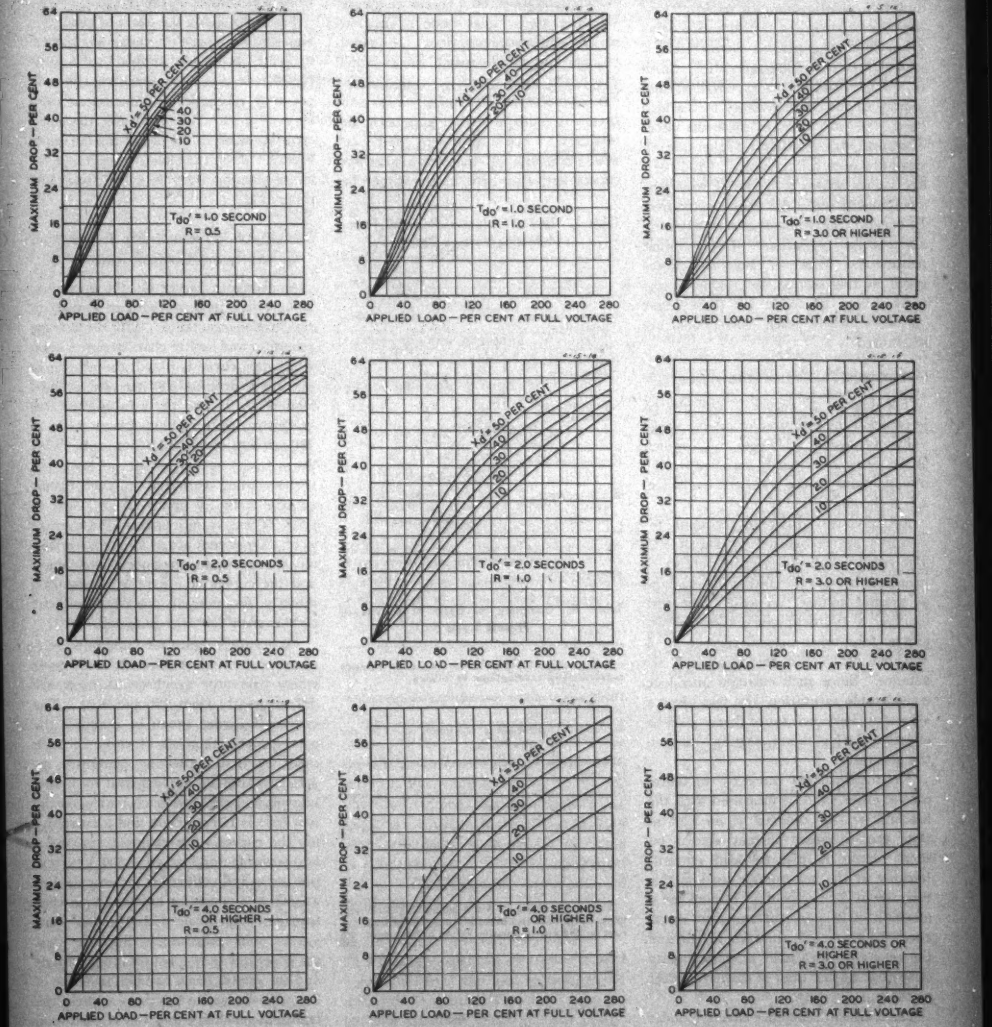


Figure 1. Voltage drop versus suddenly applied load for generators with various transient reactances, x_d', time constant, T_{do}', and nominal exciter response, R

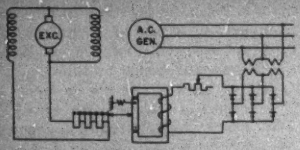


Figure 2. Essential components of excitation system with direct-acting regulator and self-excited exciter

motor or other load are discussed. These are taken up in order, consideration being given first to generator characteristics; second, to exciter characteristics; third, to voltage-regulator characteristics; and fourth, to the characteristics of the load itself. In each case, to show the effect of a particular quantity, all other quantities have been held constant at the average values shown in Table II while the one quantity under discussion was varied. In general, the voltage drop is but little affected by variations of the minor parameters. However, from the curves given in this section, approximate corrections can be made for these lesser variables where such corrections are warranted.

Generator Transient Reactance, x_d'

The curves of Figure 1 are plotted in terms of the saturated or rated-voltage value of transient reactance, $x_{d'sat}$, which is the value customarily supplied by the manufacturer as the transient reactance, x_d', of the machine.

Actually two different transient reactances are recognized by the AIEE. The rated-voltage transient reactance is measured by short-circuiting the machine at normal voltage, no load. The test involves a transient current of, for example, four times normal current for a machine of 25 per cent transient reactance. Since such currents introduce considerable saturation, the test gives a somewhat lower reactance than would be effective during motor-starting duty on the generator.

The rated-current transient reactance, on the other hand, is measured with the machine voltage reduced at no load so that the transient current drawn on short circuit is just full-load current. Because of the low voltage used in this test, about 25 per cent of normal for a machine of 25 per cent transient reactance, the degree of saturation is less, and the reactance measured is consequently somewhat higher than is effective under motor-starting duty.

The transient reactance effective under usual motor-starting conditions lies between the rated-voltage and rated-current transient reactances. It has been found from test and also by analysis to be greater than the rated-voltage value by approximately one third of the difference between the rated-voltage and rated-current values. Figure 5 shows a test curve of generator voltage under suddenly applied load without regulator action. Calculated curves based on rated-voltage and rated-current values of reactance, $x_{d'sat}$ and $x_{d'unsat}$, show that calculations based on a reactance greater than the rated-voltage value by one third of the difference between the rated-voltage and rated-current values would practically have coincided with the test curve, except for the initially high subtransient component that appears in the test curve. The subtransient component was neglected in the two calculated curves and elsewhere in the paper because subtransient effects are normally over before maximum voltage dips occur.

Table I. Typical Values of Principal Factors Affecting Voltage Drop*

	x_d	$x_{d'sat}$	x_p
Two-pole turbine generators	1.10	0.155	0.09
	0.95–1.45	0.12–0.21	0.07–0.14
Four-pole turbine generators	1.10	0.23	0.17
	1.00–1.45	0.20–0.28	0.12–0.24
Salient-pole generators	1.15	0.37	0.32
	0.60–1.45	0.20–0.50	0.17–0.40
Exciter response		1.0	
		0.5–3.0	
Regulator operating time, seconds		0.05	
		0.03–0.10	

* Reactances are per unit. Values below the line give the range of values, while those above give an average value.

Table II. Summary of Basis of Curves of Figures 1 and 6

The curves of Figure 1 are based on average constants and assumptions as follows:

Direct-axis transient reactance x_d used in calculation $= 1.07 x_{d'sat}$.

Direct-axis synchronous reactance $x_d = 1.20$ per unit

Quadrature-axis synchronous reactance $x_q = 0.75$ per unit

Excitation required for saturation at no load, normal voltage —0.20 per unit

Regulator equivalent operating time—0.05 second

Added load—constant impedance, 0.35 power factor

Initial load—zero

Regulating system—shown in Figure 2

The curves of Figure 6 are based on the foregoing assumptions and in addition the following, except for the one parameter varied in each case:

$x_{d'sat} = 0.25$ per unit, $x_{d'} = 1.07 \times x_{d'sat} = 0.268$ per unit

$T_{do'} = 3.0$ seconds

Exciter response $= 1.0$

Added load—a 0.35 power-factor impedance which would draw 100 per cent of generator full-load current rating at normal voltage

The ratio of rated-current to rated-voltage transient reactance varies from 1.14 for average standard machines to 1.3 or greater for more highly saturated lightweight machines built for mobile service. Thus, "greater by one third of the difference" means from 1.04 to 1.10 times the rated-voltage value, $x_{d'sat}$. The curves of Figure 1 were calculated using a reactance of $1.07\ x_{d'sat}$.

Figure 6a shows the effect of generator transient reactance on maximum voltage drop for 100 per cent applied load. Doubling the transient reactance from 20 to 40 per cent multiplies the maximum drop by only 1.38. This illustrates the small error involved in the use of the curves of Figure 1 when the effective reactance for motor-starting duty is other than 1.07 times $x_{d'sat}$.

Generator Synchronous Reactance, x_d, and Short-Circuit Ratio

As shown in Figure 6b, the maximum voltage drop increases with an increase in synchronous reactance. With the average generator and exciter characteristics upon which this curve is based, the change in maximum drop at 100 per cent applied load is about two parts in twenty five as x_d is varied from 120 per cent down to 100 per cent or up to 140 per cent. With 20 per cent saturation at no load, the corresponding variation in short-circuit ratio is from 1.0 up to 1.2 or down to 0.86. These variations from the average x_d of 120 per cent are as large as are usually encountered among normal machines, and the curves of Figure 1 can be used directly for normal machines without serious error for most purposes.

An accurate figure for maximum voltage drop may be required in some cases where generator synchronous reactance differs greatly from 120 per cent. The curves of Figure 1 can be used for the precise determination of drop in such cases by first expressing generator reactances and the applied load on a new kilovolt-ampere base, such that x_d on the new base is 120 per cent, and then applying the curves. For example, suppose a low-power-factor load of 1,500 kva (expressed at full voltage) is to be applied to a 3,000-kva generator having 30 per cent transient reactance and 150 per cent synchronous reactance. Suppose that the generator time constant is 4.0 seconds and the exciter has a nominal response of 1.0. To determine the drop, express the transient reactance and the applied load on the kilovolt-ampere base upon which x_d is 120 per cent. The base in this case

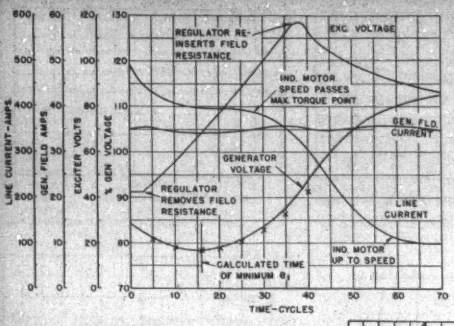


Figure 3. Typical voltage-dip curve obtained from test with calculated points (crosses) for comparison

Added load 0.97 per unit at 0.41 power factor to 375-kva generator initially operating at 0.20 per-unit load, 1.0 power factor

will be $3,000 \times 120/150 = 2,400$ kva. On this base the transient reactance x_d' is $30 \times 2,400/3,000 = 24$ per cent, and the applied load is $1,500/2,400 = 62.5$ per cent. From the curves of Figure 1, the maximum voltage drop is 15 per cent for 62.5 per cent load applied to a generator having 24 per cent transient reactance, a time constant of 4.0 seconds, and an exciter of 1.0 nominal response. This same maximum drop would be obtained with the machine and load under consideration.

Generator Open-Circuit Time Constant, T_{do}'

The maximum drop decreases as the time constant is increased, as shown in Figure 6c. In general, the time constant is longer for larger machines, typical values being given in Table I. In view of the relatively large effect of variations in this factor, it was selected as one of the four main parameters in the calculation of Figure 1.

Generator Quadrature-Axis Synchronous Reactance, x_q, and Saturation, s

As shown in Figure 6d, variation of x_q has practically no effect on the maximum voltage drop. This effect would be expected for low-power-factor loads, because for such loads practically all the phenomena take place in the direct axis, quadrature-axis effects being relatively unimportant.

The increased excitation required for saturation in normal machines as compared with that which would be required with no saturation enters into the voltage-drop calculation. An excitation at no-load normal voltage 20 per cent greater than that required to produce normal voltage on the air-gap line was used in calculating the curves. Figure 6e shows that the drop is not altered materially by varying this factor from zero to 40 per cent. The latter figure represents a machine having above-average saturation.

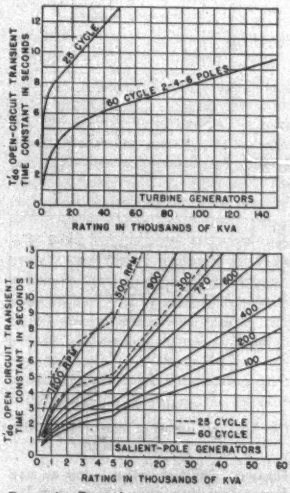


Figure 4. Typical open-circuit time constants of machines of different sizes and speeds

Exciter Response

The voltage of a self-excited exciter builds up at an accelerating rate in an exponential curve until limited by saturation. The time constant of the exponential increase is directly related to response as defined by the American Standards Association, as will be shown in a later section. Below saturation the exciter voltage increases 2.718 times per time constant.

As shown in Figure 6f, maximum generator voltage drop is reduced sharply by an increase in response up to 1.0, but beyond this point the gain is not as pronounced. The curve is based on a generator time constant of 3.0 seconds. With shorter generator time constants, increases in the exciter response above 1.0 will reduce the drop more than indicated by the curve.

Regulator Operating Time

After the voltage drops, the regulator requires a finite time to short-circuit the resistance in the exciter field circuit. While this is not an instantaneous process, an equivalent regulator operating time can be used with negligible error. Sudden short-circuiting of the resistance at the regulator operating time is equivalent to the actual gradual removal of resistance. The curves of Figure 1 are based on a "regulator operating time" of 0.05 second, a fairly representative value for the direct-acting-type regulator. As shown in Figure 6g the drop is increased only 0.7 per cent out of 25 per cent, if this time is doubled; consequently, no great error is made in using the curves of Figure 1, based on a regulator operating time of 0.05 second, for cases where operating time may be slightly greater or less than this figure.

Initial Load

The initial load on a generator influences the voltage drop when additional load is suddenly applied. As shown in Figure 6h, a static or constant-impedance initial load reduces the voltage drop caused by suddenly applied load. However, a load that draws additional current as voltage decreases may increase the voltage drop. Such loads will be referred to herein as "dynamic" loads. For example, a running induction motor may drop slightly in speed during the voltage dip so that it actually draws an increased current and thereby increases the maximum voltage drop. The dynamic initial load curve of Figure 6h is based on an initial load that draws constant kilowatts and power factor as the voltage varies.

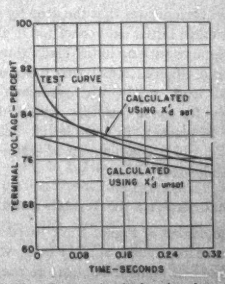
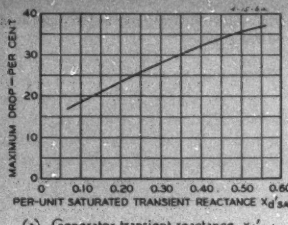
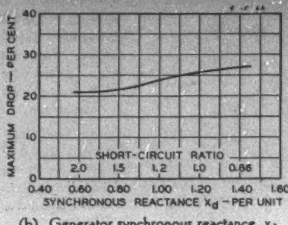


Figure 5. Test and calculated voltage-time curves of an a-c generator with a suddenly applied reactive load

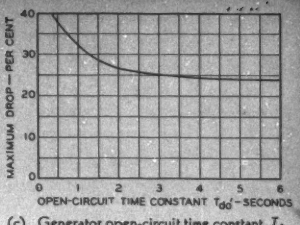
No regulator action. Subtransient effects were not considered in calculated curves



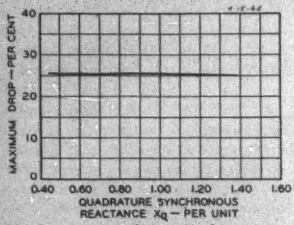
(a). Generator transient reactance, $x_{d'sat}$



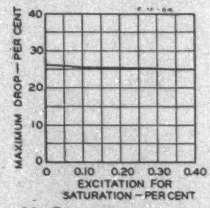
(b). Generator synchronous reactance, x_d



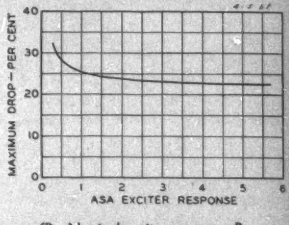
(c). Generator open-circuit time constant, T_{do}



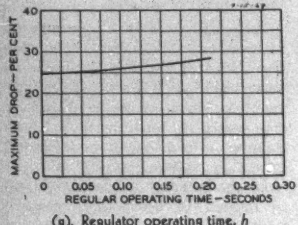
(d). Generator quadrature synchronous reactance, x_q



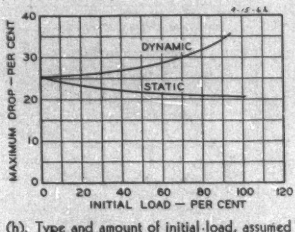
(e). Generator saturation, s



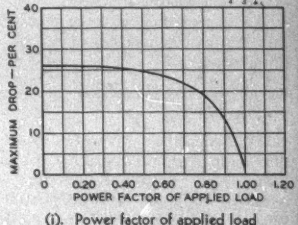
(f). Nominal exciter response, R



(g). Regulator operating time, h



(h). Type and amount of initial load, assumed at 0.80 power factor



(i). Power factor of applied load

Figure 6. Effect of various factors on maximum voltage drop when 100 per cent low-power-factor load is suddenly applied to an a-c generator

For each curve only the factor given as the abscissa was varied, other factors being kept constant at values given in Table II

An initial load is usually some combination of static and dynamic loads, and the voltage drop with additional suddenly applied load is therefore intermediate between the drop with an initial load entirely dynamic in character and the drop with entirely static initial load. Figure 6h indicates that the drop for such an average initial load condition is about the same as with no initial load; thus the curves of Figure 1, which were based on no initial load, apply with sufficient accuracy for most purposes where initial load is present, if such initial load is made up of a combination of static and dynamic load.

Characteristics of Applied Load

The curves of Figure 1 are based on a constant-impedance applied load, which as has been pointed out can be used to represent an induction motor during the starting period. In the curves the power factor of applied load was taken as 35 per cent, a typical motor-starting power factor. The maximum voltage drop is practically the same for all power factors from zero to 40 per cent but decreases rapidly for power factors above this figure, as indicated in Figure 6i.

Equations for Maximum Voltage Drop

In this section equations are derived into which machine and load quantities can be substituted to give directly the minimum voltage of the voltage-time curve of a generator under suddenly applied load. A simple mathematical expression for the build-up of voltage of a self-excited exciter is derived, based on the ASA definition of nominal response. This expression is substituted into the differential equation of generator internal voltage under closed-circuited armature conditions, and the differential equation is solved, yielding an expression for the internal voltage as a function of time. An equation for the time at which the internal voltage is at its minimum value is derived. The time of minimum voltage, determined by means of the latter equation, can be substituted into the generator-voltage equation to determine the minimum internal voltage, from which the terminal voltage can readily be determined.

Analytical Approximation of Exciter Build-Up

The nominal response of an exciter is defined as the ratio to the nominal slip-ring voltage of the slope in volts per second of the straight line, beginning at nominal slip-ring voltage on the voltage–time curve and continuing for one-half second, under which the area is the same as the area under the actual no-load build-up curve over the same half-second in-

Table III. Characteristics of Generators and Exciters Used in Tests

	Group 1	Group 2
Transient reactance, $x_d'_{sat}$	0.218 per unit	0.170 per unit
Synchronous reactance, x_d	0.932	0.715
Quadrature synchronous reactance, x_q	0.566	0.48
Open-circuit time constant T_{do}'	1.61 seconds	1.40 seconds
Excitation required for saturation at no-load normal voltage	0.183 per unit	0.312 per unit
Exciter response	2.16	2.77

terval. Nominal slip-ring voltage is the voltage required at the slip rings of the main generator to generate full load at rated power factor. An illustrative calculation of nominal exciter response is given in Figure 7.

The definition of nominal response suggests a means of approximating analytically the voltage-time curve of an exciter when the only information available about the exciter is its nominal response. In a self-excited exciter, terminal voltage builds up with an exponentially rising characteristic, following this characteristic until saturation limits it to a ceiling value. Over the unsaturated region of build-up, the voltage can be represented by an expression of the form

$$e_z = e_1 \epsilon^{t/T_e} \tag{1}$$

in which e_1 is the initial value of e_z, that is, the voltage at $t=0$, $\epsilon=2.718$, and T_e is a time constant depending upon exciter field and armature characteristics. Equation 1 can be used to represent the effect of an actual exciter by choosing the time constant T_e so that the resulting curve has the same nominal response as the actual exciter build-up curve. Such a curve, having the same nominal response, will then follow fairly closely the actual exciter curve over the half-second range beginning at nominal slip-ring voltage, and it can be used as a good approximation for voltages below nominal slip-ring voltage. Maximum voltage dip normally occurs with small and medium sized generators within one-quarter to one second after sudden application of load, and any departure of the analytical approximation from the actual curve within such times will be negligible. Use of the nominal response, which is based on the no-load build-up curve of the exciter, to represent exciter build-up under load conditions, is a justifiable approximation for usual exciter proportions. This will be shown later by comparison of tests with calculations involving this approximation.

The curve of Figure 8 gives directly values of T_e as a function of nominal response. The derivation of this curve is given in Appendix 1. Exciter build-up can be represented by substituting into equation 1 the value of T_e from Figure 8 corresponding to the response of the actual exciter. The initial exciter voltage, determined by the excitation requirements of the main generator under load conditions preceding sudden application of additional load, should be substituted for e_1. Figure 7 gives a comparison of a typical exciter build-up curve with its analytical approximation, equation 1.

Generator-Field-Circuit Equation, Armature Open-Circuited

In the analysis of generator voltages and currents that follows, attention will be confined to effects in the main field and armature circuits, that is, subtransient currents in damper windings and pole faces will be neglected. The reason for this is that the time constant of decay of these subtransient effects is so short (on the order of two or three cycles) that their duration is negligible compared to the duration of the transient component. The transient time constants of normal machines and the time required for normal exciters to build up are so long by comparison that subtransient effects will have disappeared after a sudden change in the armature circuit long before the lowest point of the voltage dip is reached.

The differential equation for the field circuit of a generator with open-circuited armature is that for a simple series circuit with inductance and resistance:

$$L\frac{di_f}{dt} + ri_f = e_z \tag{2}$$

In equation 2, L is field-circuit inductance, i_f is field current, r is field resistance, and e_z is exciter voltage, fixed or variable. If this equation is divided through by r, and L/r is denoted by T_{do}', the time constant of the field circuit when the armature is open-circuited, it can be written

$$T_{do}'\frac{di_f}{dt} + i_f = \frac{e_z}{r} \tag{3}$$

If i_f in equation 3 is expressed as a per-unit quantity in which one unit is the amount of field current required to produce unit voltage at no load on the air-gap line of the machine, it becomes identical with the per-unit value of e_d, the direct-axis synchronous internal voltage. That is, for each per-unit of value field current there is an equal per-unit value of e_d. Likewise e_z/r can be expressed in per-unit terms where one unit is the field current required to produce unit voltage on the air-gap line. If one unit of e_z is taken as the exciter voltage required to force unit field current through the field resistance r, equation 3 can be rewritten in per-unit terms as follows:

$$T_{do}'\frac{de_d}{dt} + e_d = e_z \tag{4}$$

Field-Circuit Equation With Closed-Circuited Armature

When a sudden change takes place in the armature circuit of a generator, nearly all the internal voltages of the machine, including e_d, undergo an instantaneous change. The one quantity that does not change instantaneously during a transition from one operating condition to another is e_d'; the direct-axis transient internal voltage. This quantity is proportional to the total flux linkages with the field winding, which cannot undergo an instantaneous change.

The fact that e_d' does not change during a transition makes it a convenient quantity to use in analyzing the effect of sudden load changes upon terminal voltage. The initial value of e_d' can be determined from the original operating conditions. This initial value can be used as a boundary condition in the solution of a differential equation for e_d' after a transition, and the resulting expression can be converted to terminal voltage by use of the new circuit constants.

Wagner[1] has given the relation between e_d and e_d' under closed-circuited armature conditions as

$$e_d = e_d' \frac{r_t^2 + x_{dt}x_{qt}}{r_t^2 + x_{dt}'x_{qt}} \tag{5}$$

In equation 5 the subscript t indicates the sum of a machine quantity and an external load quantity, that is

$$x_{dt}' = x_d' + x_{ext}$$
$$r_t = r_a + r_{ext}$$

and so on.

In modifying equation 4, which applies only when the armature is open-circuited, to get an expression for closed-circuit conditions, the change in the time constant T_{do}' caused by mutual effects between the armature and field circuits must be considered. Wagner has shown[2] that under closed-circuit conditions T_{do}' can be modified to give the equivalent closed-circuit time constant T_d' as follows:

$$T_d' = \frac{r_t^2 + x_{dt}'x_{qt}}{r_t^2 + x_{dt}x_{qt}} T_{do}' \tag{6}$$

Substituting the closed-circuit time constant T_d' for T_{do}' in equation 4 and substituting for e_d its value in terms of e_d' from equation 5, we get

$$T_{do}'\frac{de_d'}{dt}+\frac{T_{do}'}{T_d'}e_d'=e_z \tag{7}$$

which is the differential equation for e_d' under closed-circuited armature conditions.

Saturation

In the derivation of equation 7 saturation was neglected and e_d was assumed to be equal under steady-state conditions to e_z. Equation 7 can be corrected for the effect of saturation by subtracting directly from e_z an amount of excitation corresponding to that used in overcoming saturation as the internal voltages of the machine vary.

In the graphical method of determining the voltage-time behavior of generators under suddenly applied load,[1] a step-by-step correction for saturation is made in the exciter voltage e_z as the voltage behind the Potier reactance of the generator varies. This correction, which is subtracted directly from e_z, is the per-unit amount of excitation required for saturation on the no-load saturation curve at voltages corresponding to instantaneous values of the Potier voltage e_p. Making the same correction in equation 7, calling the saturation component of excitation s and subtracting it from e_z we get

$$T_{do}'\frac{de_d'}{dt}+\frac{T_{do}'}{T_d'}e_d'=e_z-s \tag{8}$$

Calculation of a large number of specific cases using the graphical method indicates that over a wide range of conditions the correction s does not vary greatly from its value at no-load normal voltage. Analysis shows that this can be expected to occur for any normal range of machine constants and applied loads. For these reasons the saturation correction s has been assumed for convenience in solving equation 8 to be constant and equal to the per-unit amount of excitation required to overcome saturation at normal voltage no load. One unit of excitation, as previously noted, is the amount required to produce rated voltage on the air-gap line of the no-load saturation curve. Since the saturation correction s is a small quantity subtracted from the much larger quantity e_z, the error introduced by assuming s constant is small. The slight effect on the maximum voltage drop of varying the quantity s over a wide range is shown in Figure 6e, which further confirms the assumption that an average figure can be assumed for s without serious error.

Generator Voltage-Time Equation

In Appendix 2, equation 8 is solved under the assumption of constant saturation, e_z being expressed in the form of equation 1. The resulting expression for the direct-axis transient internal voltage as a function of time is

$$e_d'=\left[\frac{e_1T_d'^2\epsilon^{\frac{h}{T_d'}}}{T_{do}'(T_s+T_d')}-\frac{(e_1-s)T_d'}{T_{do}'}+e_{d1}'\right]\epsilon^{-\frac{t}{T_d'}}+\left[\frac{e_1T_d'T_s}{T_{do}'(T_s+T_d')}\right]\epsilon^{\frac{t-h}{T_s}}-\frac{sT_d'}{T_{do}'} \tag{9}$$

in which e_1 is the initial exciter voltage in per unit, determined by the excitation requirements of the generator under load conditions preceding the load change; T_d' is the generator transient time constant in seconds, defined by equation 6; T_{do}' is the generator open-circuit time constant in seconds; T_s is the value read from Figure 8 corresponding to the response of the exciter; h is the equivalent regulator operating time; s is the per-unit excitation required for saturation at normal voltage on the no-load saturation curve of the generator; and e_{d1}' is the initial value of direct-axis transient internal voltage, calculated from the operating condition of the generator previous to the load change. For a generator initially operating at normal voltage, a per unit current i, and a power-factor angle ϕ, e_{d1}' in per unit will be

$$e_{d1}'=\frac{1+(x_d'+x_q)i\sin\phi+x_qx_d'i^2}{\sqrt{1+2x_di\sin\phi+x_d^2i^2}} \tag{10}$$

For a machine operating initially at no load, $i=0$ and $e_{d1}'=1.0$. Equation 10 is derived in Appendix 3. The voltage e_d' given by equation 9 can be converted to terminal voltage e_t by the following expression.[1]

$$e_t=\frac{\sqrt{(x_{qt}^2+r_t^2)(x_{ext}^2+r_{ext}^2)}}{x_{dt}'x_{qt}+r_t^2}e_d' \tag{11}$$

Most convenient use can be made of equation 9 in determining minimum e_t by substituting in it directly the value of t at which e_d' and e_t have their minimum values. By differentiating equation 9, setting the result equal to zero, and solving for t, it can be shown that the time at which these minimum values occur is

$$t=\frac{T_sT_d'}{0.434(T_s+T_d')}\log_{10}\left[\frac{e_1T_d'\epsilon^{\frac{h}{T_d'}}-(e_1-s-T_{do}'e_{d1}'/T_d')(T_s+T_d')}{e_1T_d'\epsilon^{-\frac{h}{T_s}}}\right] \tag{12}$$

By substituting t from equation 12 into equation 9 and applying equation 11, the minimum terminal voltage e_t can be determined directly.

Experimental Confirmation of Equations

The validity of the equations just derived has been checked by oscillographic tests. Two groups of tests were made, one on each of two complete generator, exciter, and regulator setups. The combinations were in both cases identical in their essential parts to the setup shown in Figure 2.

In the first group of tests a large induction-motor starting load was applied to a 375-kva generator operating at various initial loads. The locked-rotor inrush of the motor at rated generator voltage was 363 kva, or 0.97 per unit of generator rating, at a power factor of 0.41. Exciter response was 2.16, and the operating time of the regulator was 0.05 second. Characteristics of the generator used in this group of tests are given in Table III.

A typical set of curves from an oscillogram made during this group of tests is shown in Figure 3. In this case the initial load on the generator was 0.20 per unit at unity power factor. Points from the voltage-dip curve calculated by means of equation 9 are shown for comparison. The calculated curve coincides closely with the test curve at minimum voltage and up to the time at which induction-motor speed approaches the maximum-torque point. The time of minimum voltage, determined by means of equation 12, coincides almost exactly with the actual time of minimum voltage from the oscillogram.

Figure 9 shows a representative test result from the second group of tests. In this group a 386-kva motor-starting load was applied to a 187-kva generator, an added load of 2.06 per unit. For the test shown in Figure 9, the generator was operating initially at no load. Agreement of the calculated points with test results is close up to the point at which motor impedance changes.

The two tests presented were chosen at random from the two groups of tests made. Application of the equations in the determination of maximum voltage

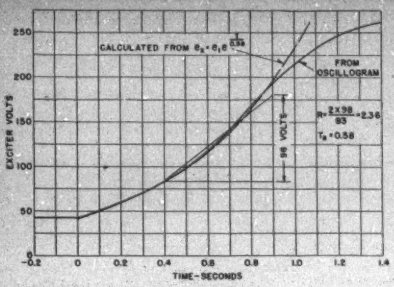
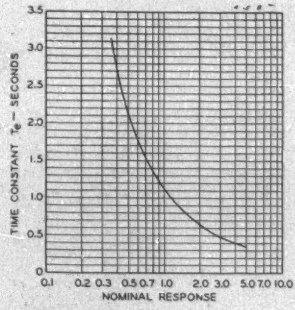


Figure 7. Voltage build-up curve of a self-excited exciter, showing method of calculating response

Nominal slip-ring voltage, 83 volts. Comparison of test curve with analytical approximation

Figure 8 (below). Time constant T_e for self-excited exciter versus nominal response



drops in other tests of these two groups as well as to several other generator setups indicates that the equations can be expected to give maximum voltage drops well within the accuracy limits usually required in engineering applications.

Conclusions

As a result of the studies described in this paper the following conclusions have been reached regarding the importance of various factors affecting voltage drop with suddenly applied low-power-factor load:

1. In the generator, the transient reactance and the open-circuit time constant are of prime importance. Reasonable variations in synchronous reactance have less effect. A method is presented of correcting for wide variations in synchronous reactance when using the voltage-drop curves. Variations in quadrature reactance and saturation have practically no effect on maximum drops.

2. For self-excited exciters the nominal response adequately expresses for practical cases the effect of exciter characteristics upon maximum voltage drops.

3. Regulator performance insofar as it affects maximum voltage drop is fully defined by the time required for the regulator to short-circuit the regulating resistance after a drop in voltage.

4. Depending upon whether it is static or dynamic in character, the initial load may reduce or increase the voltage drop slightly; consequently, the assumption of no initial load gives a good representation of average initial load conditions.

5. Variations in the power factor of the applied load from zero to 40 per cent have a negligible effect on the maximum drop. This range includes normal starting power factors for squirrel-cage induction motors, so that the curves apply for usual motor-starting problems.

It has been generally concluded that maximum voltage drops can be expressed in terms of the four main parameters, generator transient reactance, generator open-circuit time constant, exciter response, and magnitude of suddenly applied load.

Mathematical expressions for generator voltage as a function of time have been derived, based on the assumptions of constant generator saturation and the representation of exciter build-up as an exponential. These approximations are shown to be justified. The curves of voltage drop were calculated using these expressions.

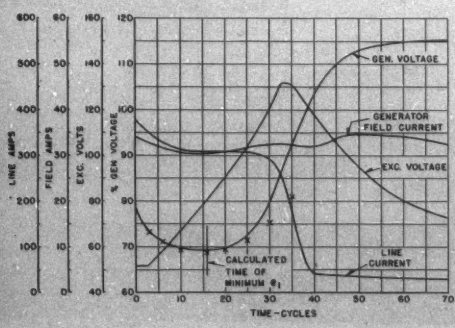


Figure 9. Comparison of calculated voltage-dip curve (crosses) with voltage-dip curve obtained from test

Added load 2.06 per unit at 0.40 power factor to 187-kva generator operating initially at no load

Appendix I. Derivation of Curve of Exciter Time Constant T_e

From the definition of nominal response, the area in Figure 10 under the straight line between 0 and 0.5 second equals the area under the exciter build-up curve over the same period, and the slope of the straight line is the nominal response times the nominal slip-ring voltage, or Re_n. Under the assumption made in the text that exciter voltage rises exponentially, these relations can be expressed as follows:

$$\int_0^{0.5} e_n e^{t/T_e} dt = \frac{Re_n}{8} + \frac{e_n}{2} \qquad (13)$$

Integrating equation 13 and solving for R, we get

$$R = 8T_e(e^{1/2T_e} - 1) - 4 \qquad (14)$$

The curve of Figure 8 was plotted from the relation between R and T_e given by equation 14.

Appendix II. Solution of Differential Equation for e_a'

In the operational solution that follows, mathematical notation and the method of solution correspond to that used in reference 3. In this notation $H(t)$ represents the Heaviside unit function, and $H(t-h)$ represents the delayed unit function, that is, the function which is zero for t less than h and equal to unity for t greater than h.

The equation to be solved is equation 8. The quantity $e_g - s$ on the right-hand side must be expressed as a function of time. If the regulator operating time is called h, and if it assumed that the exciter build-up curve can be represented by the analytical approximation given by equation 1, the curve of exciter voltage after application of load will be as shown in Figure 11. The

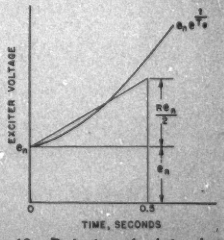


Figure 10. Derivation of relation between response and time constant T_e

Area under straight sloping line equals area under curve between 0 and 0.5 second

function shown in this figure can be expressed in terms of unit functions as follows:

$$e_x = e_1 H(t) - e_1 H(t-h) + e_1 \epsilon^{\frac{t-h}{T_e}} H(t-h) \quad (15)$$

Substituting equation 15 into equation 8, dividing by T_{do}', and multiplying s (assumed constant) by the unit function, we get

$$\frac{de_q'}{dt} + \frac{1}{T_d'} e_q' = \frac{1}{T_{do}'}\left[e_1 H(t) - e_1 H(t-h) + e_1 \epsilon^{\frac{t-h}{T_e}} H(t-h) - sH(t) \right] \quad (16)$$

Writing equation 16 in operational form (replacing d/dt by p), adding the operational form of e_{q_1}', the initial value of e_q', and dividing by $p+1/T_d'$ we get

$$e_q' = \frac{e_1 - s}{T_{do}'\left(p+\frac{1}{T_d'}\right)} - \frac{e_1 \epsilon^{-ph}}{T_{do}'\left(p+\frac{1}{T_d'}\right)} + \frac{pe_1 \epsilon^{-ph}}{T_{do}'\left(p+\frac{1}{T_d'}\right)\left(p-\frac{1}{T_e}\right)} + \frac{pe_{q_1}'}{p+\frac{1}{T_d'}} \quad (17)$$

Substituting equation 17 into the Bromwich–Wagner complex integral to get e_q' as

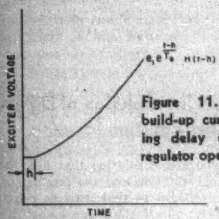


Figure 11. Exciter build-up curve, including delay caused by regulator operating time

a function of t, changing p to the complex parameter z, we have

$$e_q' = \frac{1}{2\pi i}\int_{Br_1} \frac{(e_1 - s)\epsilon^{zt} dz}{T_{do}'\left(z+\frac{1}{T_d'}\right)z} - \frac{1}{2\pi i}\int_{Br_1} \frac{e_1 \epsilon^{-zh}\epsilon^{zt} dz}{T_{do}'\left(z+\frac{1}{T_d'}\right)z} + \frac{1}{2\pi i}\int_{Br_1} \frac{e_1 \epsilon^{-zh}\epsilon^{zt} dz}{T_{do}'\left(z+\frac{1}{T_d'}\right)\left(z-\frac{1}{T_e}\right)} + \frac{1}{2\pi i}\int_{Br_1} \frac{e_{q_1}'\epsilon^{zt} dz}{z+\frac{1}{T_d'}} \quad (18)$$

from which, upon evaluating the complex integrals and simplifying, we obtain equation 9.

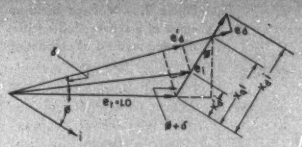


Figure 12. Two-reaction vector diagram of a salient-pole synchronous generator

Mathematically this equation is not valid for t less than h (see reference 3), but this is not important in the determination of maximum drops because the minimum value of e_q' will always occur at a value of t greater than h, that is, after the regulator has operated.

Appendix III. Derivation of Expression for Initial Value of e_q'

Figure 12 is a portion of the conventional two-reaction vector diagram for a synchronous machine. The direct-axis transient internal voltage e_q' is the projection of the transient voltage e_t upon the direct axis. That is, assuming unit terminal voltage,

$$e_q' = \cos\delta + x_d' i \sin(\phi+\delta) \quad (19)$$

Upon expanding the last term of equation 19, we get

$$e_q' = \cos\delta + x_d' i \sin\phi \cos\delta + x_d' i \cos\phi \sin\delta \quad (20)$$

From Figure 12

$$\operatorname{Tan}\delta = \frac{x_q i \cos\phi}{1 + x_q i \sin\phi} \quad (21)$$

from which

$$\operatorname{Cos}\delta = \frac{1 + x_q i \sin\phi}{\sqrt{1 + 2x_q i \sin\phi + x_q^2 i^2}} \quad (22)$$

and

$$\operatorname{Sin}\delta = \frac{x_q i \cos\phi}{\sqrt{1 + 2x_q i \sin\phi + x_q^2 i^2}} \quad (23)$$

Substituting equations 22 and 23 into equation 20, we get equation 10.

Nomenclature

Per-unit values are used for all quantities except where specifically denoted otherwise.

ϵ = 2.718
e_d = direct-axis synchronous internal voltage
e_q' = direct-axis transient internal voltage
e_{q_1}' = initial direct-axis transient internal voltage
e_q = transient internal voltage
e_n = nominal exciter voltage
e_1 = generator terminal voltage
e_x = exciter terminal voltage
e_{x_1} = initial exciter terminal voltage
h = regulator operating time
$H(t)$ = Heaviside unit function
$H(t-h)$ = delayed Heaviside unit function, that is, the function which is zero for t less than h and unity for t greater than h
i = armature current. In the Bromwich–Wagner complex integral $i = \sqrt{-1}$
i_f = field current
L = field inductance
p = parameter used in operational form of time-dependent functions
r_a = generator armature resistance
r_{ext} = external resistance, that is, load resistance at generator terminals
$r_t = r_a + r_{ext}$
R = nominal exciter response by ASA definition
s = per-unit excitation required to overcome saturation at no load, rated voltage
t = time in seconds
T_d' = short-circuit transient time constant defined by equation 6
T_{do}' = generator open-circuit transient time constant
T_e = time constant of exciter build-up
x_d = unsaturated direct-axis synchronous reactance
$x_{dt} = x_d + x_{ext}$
x_d' = direct-axis transient reactance
$x_{dt}' = x_d' + x_{ext}$
x_{ext} = external reactance, that is, load reactance at generator terminals
x_q = quadrature-axis synchronous reactance
$x_{qt} = x_q + x_{ext}$
z = complex variable parameter used in Bromwich–Wagner complex integral

References

1. Electrical Transmission and Distribution Reference Book. Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., 1942. Chapter 7, "Machine Characteristics," C. F. Wagner.
2. Effect of Armature Resistance Upon Hunting of Synchronous Machines, C. F. Wagner. AIEE Transactions, volume 49, 1930, pages 1011–26.
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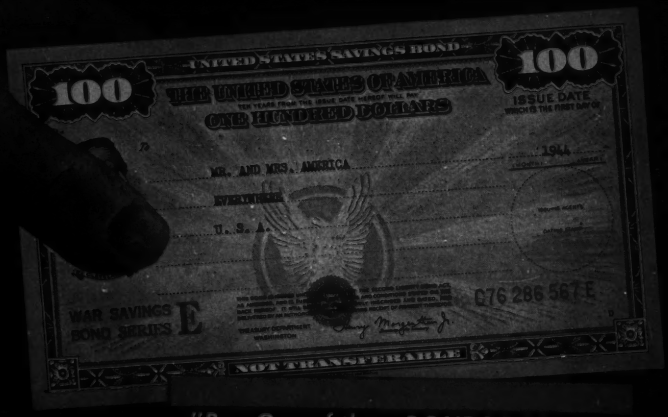

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function shown in this figure can be expressed in terms of unit functions as follows:

$$e_z = e_1 H(t) - e_1 H(t-h) + e_1 \epsilon^{\frac{t-h}{T_e}} H(t-h) \quad (15)$$

Substituting equation 15 into equation 8, dividing by T_{do}', and multiplying s (assumed constant) by the unit function, we get

$$\frac{de_d'}{dt} + \frac{1}{T_d'} e_d' = \frac{1}{T_{do}'}\left[e_1 H(t) - e_1 H(t-h) + e_1 \epsilon^{\frac{t-h}{T_e}} H(t-h) - sH(t) \right] \quad (16)$$

Writing equation 16 in operational form (replacing d/dt by p), adding the operational form of e_{d_1}', the initial value of e_d', and dividing by $p+1/T_d'$ we get

$$e_d' = \frac{e_1 - s}{T_{do}'\left(p+\frac{1}{T_d'}\right)} - \frac{e_1 \epsilon^{-ph}}{T_{do}'\left(p+\frac{1}{T_d'}\right)} + \frac{pe_1 \epsilon^{-ph}}{T_{do}'\left(p+\frac{1}{T_d'}\right)\left(p-\frac{1}{T_e}\right)} + \frac{pe_{d_1}'}{p+\frac{1}{T_d'}} \quad (17)$$

Substituting equation 17 into the Bromwich–Wagner complex integral to get e_d' as

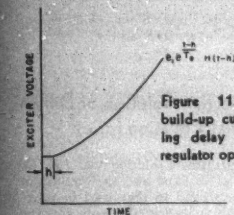

Figure 11. Exciter build-up curve, including delay caused by regulator operating time

a function of t, changing p to the complex parameter z, we have

$$e_d' = \frac{1}{2\pi i}\int_{Br_1} \frac{(e_1 - s)\epsilon^{zt} dz}{T_{do}'\left(z+\frac{1}{T_d'}\right)z} - \frac{1}{2\pi i}\int_{Br_1} \frac{e_1 \epsilon^{-zh}\epsilon^{zt} dz}{T_{do}'\left(z+\frac{1}{T_d'}\right)z} + \frac{1}{2\pi i}\int_{Br_1} \frac{e_1 \epsilon^{-zh}\epsilon^{zt} dz}{T_{do}'\left(z+\frac{1}{T_d'}\right)\left(z-\frac{1}{T_e}\right)} + \frac{1}{2\pi i}\int_{Br_1} \frac{e_{d_1}'\epsilon^{zt} dz}{z+\frac{1}{T_d'}} \quad (18)$$

from which, upon evaluating the complex integrals and simplifying, we obtain equation 9.

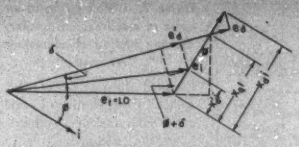

Figure 12. Two-reaction vector diagram of a salient-pole synchronous generator

Mathematically this equation is not valid for t less than h (see reference 3), but this is not important in the determination of maximum drops because the minimum value of e_d' will always occur at a value of t greater than h, that is, after the regulator has operated.

Appendix III. Derivation of Expression for Initial Value of e_d'

Figure 12 is a portion of the conventional two-reaction vector diagram for a synchronous machine. The direct-axis transient internal voltage e_d' is the projection of the transient voltage e_1 upon the direct axis. That is, assuming unit terminal voltage,

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e_1 = transient internal voltage

e_n = nominal exciter voltage

e_t = generator terminal voltage

e_z = exciter terminal voltage

e_1 = initial exciter terminal voltage

h = regulator operating time

$H(t)$ = Heaviside unit function

$H(t-h)$ = delayed Heaviside unit function, that is, the function which is zero for t less than h and unity for t greater than h

i = armature current. In the Bromwich–Wagner complex integral $i = \sqrt{-1}$

i_f = field current

L = field inductance

p = parameter used in operational form of time-dependent functions

r_a = generator armature resistance

r_{ext} = external resistance, that is, load resistance at generator terminals

$r_t = r_a + r_{ext}$

R = nominal exciter response by ASA definition

s = per-unit excitation required to overcome saturation at no load, rated voltage

t = time in seconds

T_d' = short-circuit transient time constant defined by equation 6

T_{do}' = generator open-circuit transient time constant

T_e = time constant of exciter build-up

x_d = unsaturated direct-axis synchronous reactance

$x_{di} = x_d + x_{ext}$

x_d' = direct-axis transient reactance

$x_{di}' = x_d' + x_{ext}$

x_{ext} = external reactance, that is, load reactance at generator terminals

x_q = quadrature-axis synchronous reactance

$x_{qi} = x_q + x_{ext}$

z = complex variable parameter used in Bromwich–Wagner complex integral

References

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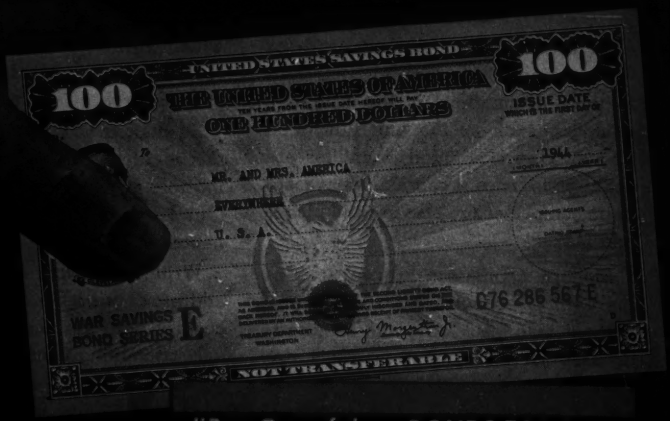

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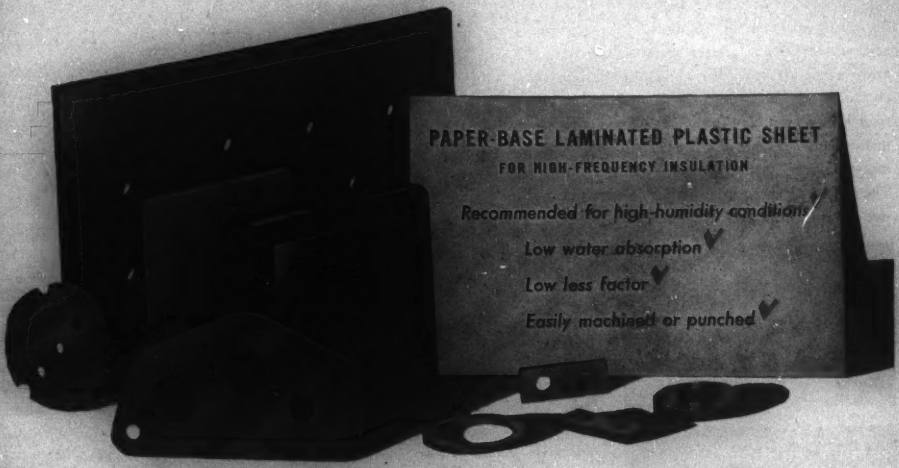

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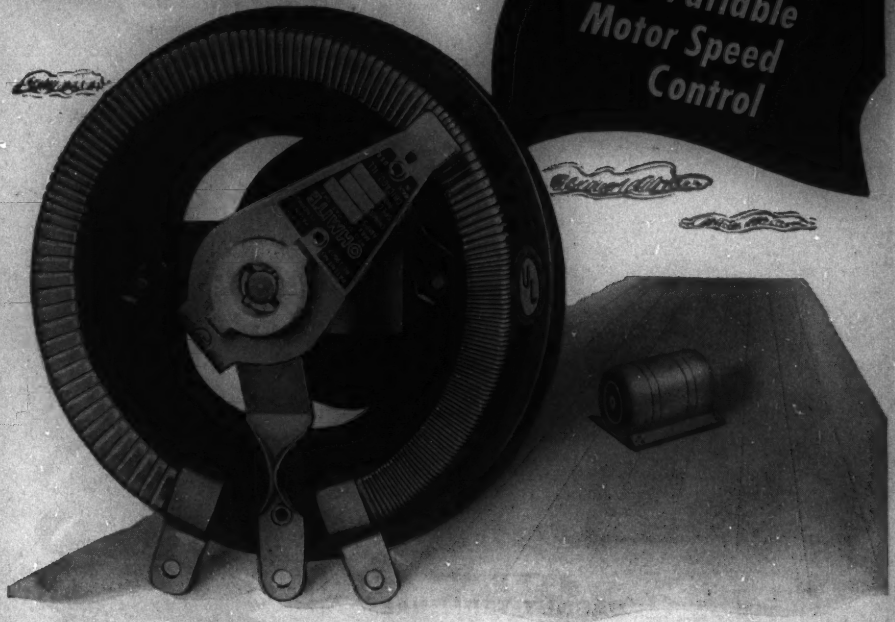

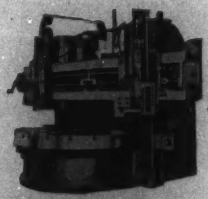

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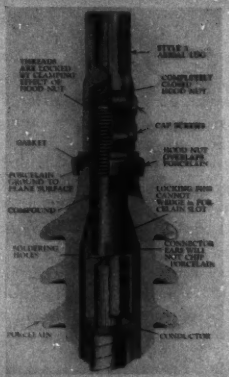

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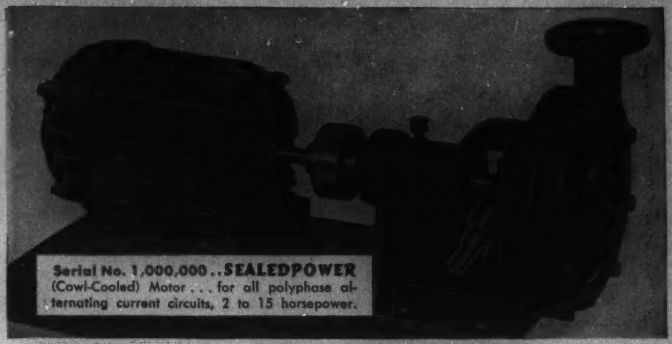

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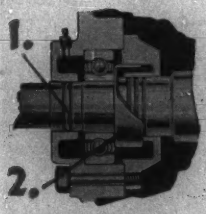

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Line styles have changed, but the ACSR on this modern line follows the original formula: steel for strength, aluminum for conductivity and long life

The first Aluminum Cable Steel Reinforced was fabricated in 1909 by Aluminum Company of America. Its size was No. 2 (No. 4 copper equivalent); a conductor now widely used in rural electrification. Six aluminum wires are stranded around one steel wire, to give a combination of high electrical conductivity, durability and high strength.

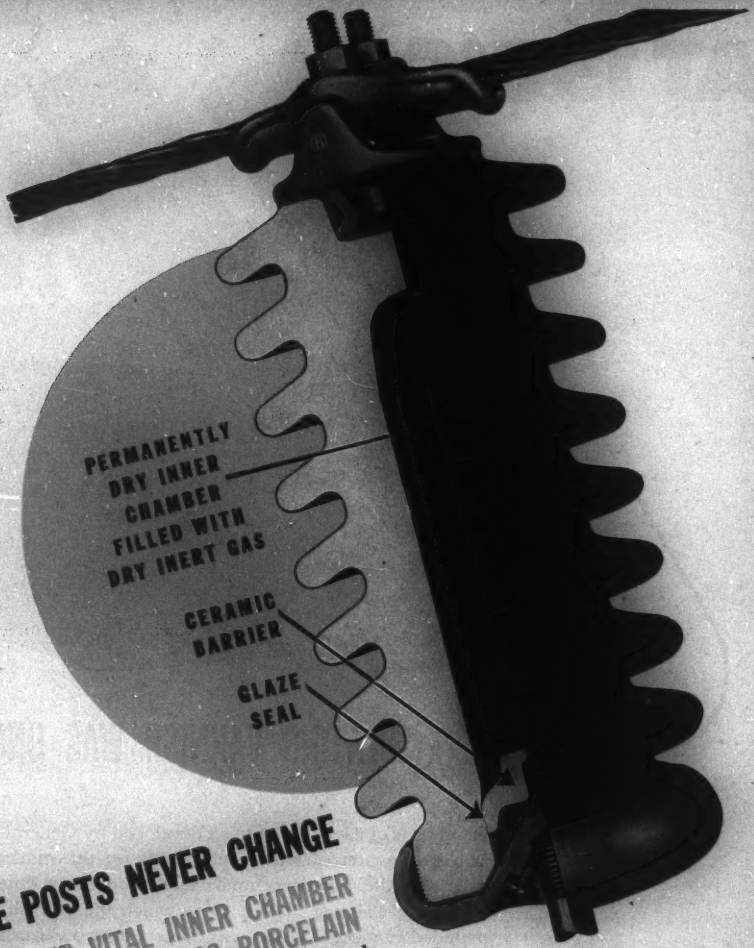
Line styles have changed considerably since then. Structures, insulators and fittings have all put on new faces. Spans have been greatly lengthened to reduce construction costs, permitting extension of service into low income areas. The advantages which gave the ACSR of 1909 acceptance by line builders have made it equally popular for these modern rural lines.

Thousands of miles of ACSR have been purchased for the construction and extension of rural lines. Builders have had the counsel of Alcoa's engineers and supervisors, receiving recommendations based on experience gained during these many years, 1909 to 1944.

This service is available to help you keep war-loaded lines on the job, or extend them into new areas. ALUMINUM COMPANY OF AMERICA, 2149 Gulf Building, Pittsburgh 19, Penna.

ALCOA A·C·S·R

ALCOA



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BECAUSE THEIR VITAL INNER CHAMBER IS SEALED IN CHANGELESS PORCELAIN

Post type insulators are just as good as their seal--and no better! Any moisture that can ever be drawn into the inner chamber will result in serious deterioration of a unit's dielectric and radio values...In the O-B line post, this seal is proved for its soundness by a prolonged vacuum holding test and its permanence is assured by use of a glazed-in porcelain barrier. Time, temperature, or any other operating condition can have no effect on the O-B ceramic seal...If your design requirements call for post insulators, specify O-B Line Posts whose all-porcelain construction makes their original electrical characteristics lasting and un-changeable as porcelain itself.

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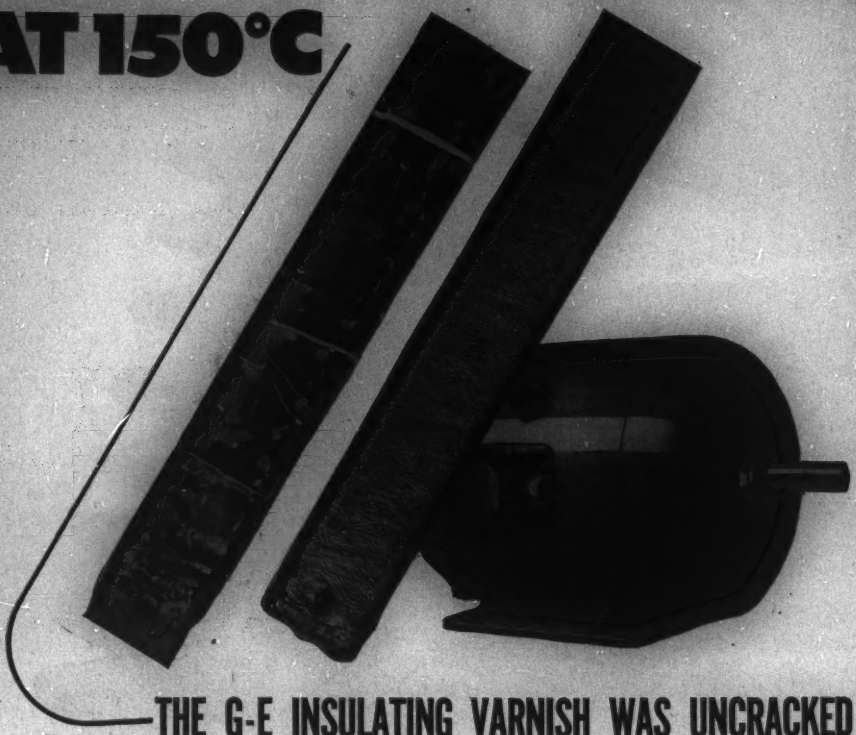

THE G-E INSULATING VARNISH WAS UNCRACKED

Rigid tests of each new varnish developed by General Electric is a prime prerequisite to placing it on the market. And, naturally, these tests are made under conditions duplicating, in a more exacting degree, those which the varnish is compounded to meet. Typical was the test of two varnishes, each intended for insulating electrical apparatus where high temperatures would be encountered. The G-E varnish withstood the accelerated heat-aging test; the other broke down.

If you face a problem in finding the correct insulating varnish for your specific needs, the engineering staff of the Resin and Insulation Materials Division of the General Electric Company will gladly cooperate with you. Consult your local G-E Distributor or write to Section M543-12, General Electric Company, Schenectady 5, New York. (Varnishes are one product in the complete line of G-E insulation materials).

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THE two condensers illustrated above are examples of two basic ceramic condenser designs developed by Erie Resistor for high voltage, high KVA applications.

Shown at the left is the Erie Type 680A transmitting condenser that is designed for 6000 volts RMS test voltage. This unit consists essentially of a number of silvered ceramic discs, each having the well known stability and temperature retrace characteristics of compensating Ceramicons, and in addition are designed to safely withstand high voltages required in this type of condenser.

The Antenna Coupling Ceramicon illustrated at the right employs the double cup design originated by Erie Resistor. In developing this unit Erie engineers successfully overcame the problems of eliminating corona and dissipating internal heat while retaining small size and simplicity of design. The specifications of this condenser, given at the right, show the high degree of perfection it has now reached.

Erie Resistor is working further on the development of similar Ceramicon designs for other applications. If you have a condenser problem connected with present day equipment, or for postwar applications involving high voltage, high KVA units, we would like to discuss Erie Ceramicons with you. Our wide experience, beginning in 1935 with the first development of ceramic condensers in this country, gives us a comprehensive background on which to base recommendations.

CHARACTERISTICS

Left: Type 680A Transmitting Ceramicon Maximum capacity 400 MMF in zero temperature coefficient, 2000 MMF in -750 P/M/°C. 10,000 volts D. C. test voltage.

Right: Erie Antenna Coupling Condenser: Maximum capacity 50 MMF in zero, 250 MMF in -750 P/M/°C temperature coefficient. Typical rating in zero coefficient, maximum R. F. current 3 amps at 3 MC and 5 amps at 9 MC at 65°C. Test voltage 6000 volts D. C.

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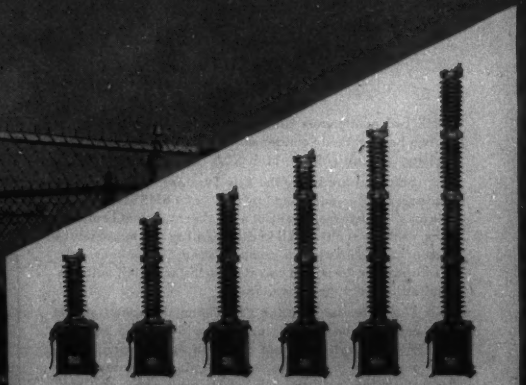

69 kv 0.003 mf | 115 kv 0.002 mf | 138 kv 0.0015 mf | 161 kv 0.0012 mf | 230 kv 0.001 mf | 287 kv 0.00075 mf

This "family" of standardized G-E Type CW carrier-current coupling capacitors and Type KA potential devices permits assemblies of any established voltage ratings.

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Coupling capacitors are the bridge between carrier equipment and the power line. They couple you to all of engineering — electric power and electronics. Joint use of lines for carrier current and power requires coupling capacitor units capable of withstanding the highest transmission line voltages and of passing the lowest carrier-frequency voltage.

G-E engineers have pioneered almost every outstanding achievement in carrier-current development. In G-E Type CW coupling capacitors they have developed coupling of extraordinary economical and electrical dependability. This coupling faithfully passes one or more carrier frequencies — regardless of lightning, line-switching surges, rain, snow and sleet. It also has permitted many existing carrier-current installations to take on extra-heavy war duties. When combined with G-E potential devices, this coupling greatly reduces the size, weight and cost of critical materials necessary to provide potential for synchronizing, relaying, and similar services.

In the past ten years, more than 5000 G-E CW capacitor units have been applied to new carrier-current installations, and modernization of old ones — without a single electrical failure.

General Electric engineers are prepared to discuss — now — the carrier-current services and equipment which may be advantageously applied to your particular light-and-power system — either toward immediate operating improvements or as a part of your expansion program. *General Electric, Schenectady, N. Y.*

* Tune in "The World Today" news evening report broadcast over C.B.S. and N.B.C. On Sunday listen in the G-E "All Girl Orchestra" on 50 *P. M.* C.B.S., over N.B.C.

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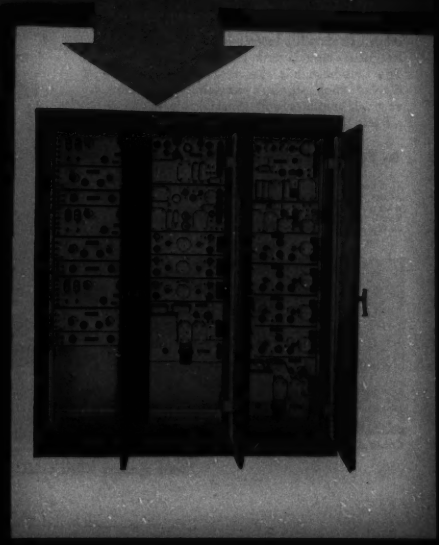

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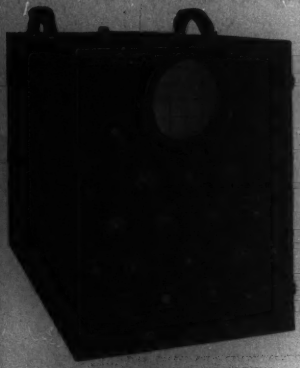
CARRIER CURRENT

FOR ARMY SERVICE BY THE POWER PEOPLE

Another DuMONT Contribution



● This latest oscillograph facilitates the investigation of transient as well as recurrent phenomena over a wide frequency range. And since a permanent record of transient phenomena is usually desirable, this instrument provides for such photographic recording by applying comparatively high accelerating potentials to its cathode-ray tube. Furthermore, a new type of beam-control circuit is incorporated.

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This oscillograph may meet your particular requirements. If not, there are other DuMont oscillographs with other characteristics that may meet your needs. You'll find them listed and described in our manual—copy on request.

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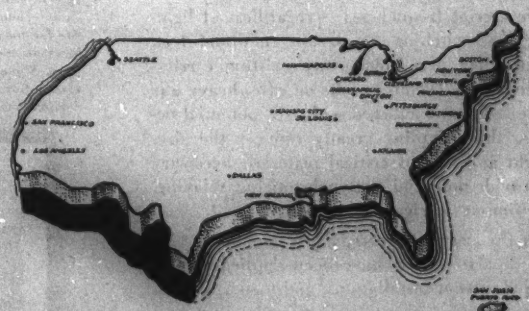

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IT'S really not much of a gamble on our part. The truth is that most of the electronic glass equipment built today comes from Corning Glass Works.

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CORNING means Research in Glass

Electronic Glassware

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When "that day" arrives, I R C will be able to supply not only voltmeter multipliers but *all* types of resistances, to meet industry's peacetime needs.

There will be no lag because of reconversion. Instead, the vast quantities of resistors being turned out for the Armed Services can be immediately diverted to civilian goods channels at prices consistent with the mass production methods now in effect.

Meanwhile, members of our engineering staff will be glad to consult with any manufacturers whose post-war plans involve resistance units. There is no obligation, and of course you can be certain all information will be held in confidence.

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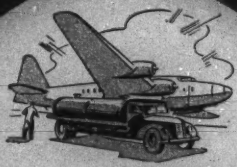

When a machine constructor chooses a grade of brush for a given motor or generator, he wants to know that the material is uniform and can be uniformly reproduced over a period of years.

In service also, operating and maintenance men want brushes that give identical results when replacements are required.

Through the years, Morganite brushes have remained uniform within close limits. Because constructors and operators know they can depend on Morganite brushes, you will find them on many heavy duty machines.

When a brush problem arises, communicate with Morganite and obtain an honest helpful answer.

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No. 5 In a Series of Factors Essential to Maximum Brush Efficiency

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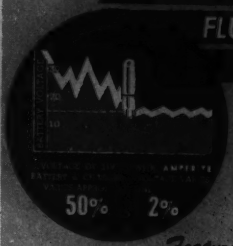

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Non-inductive paper sections in heavy tubing.

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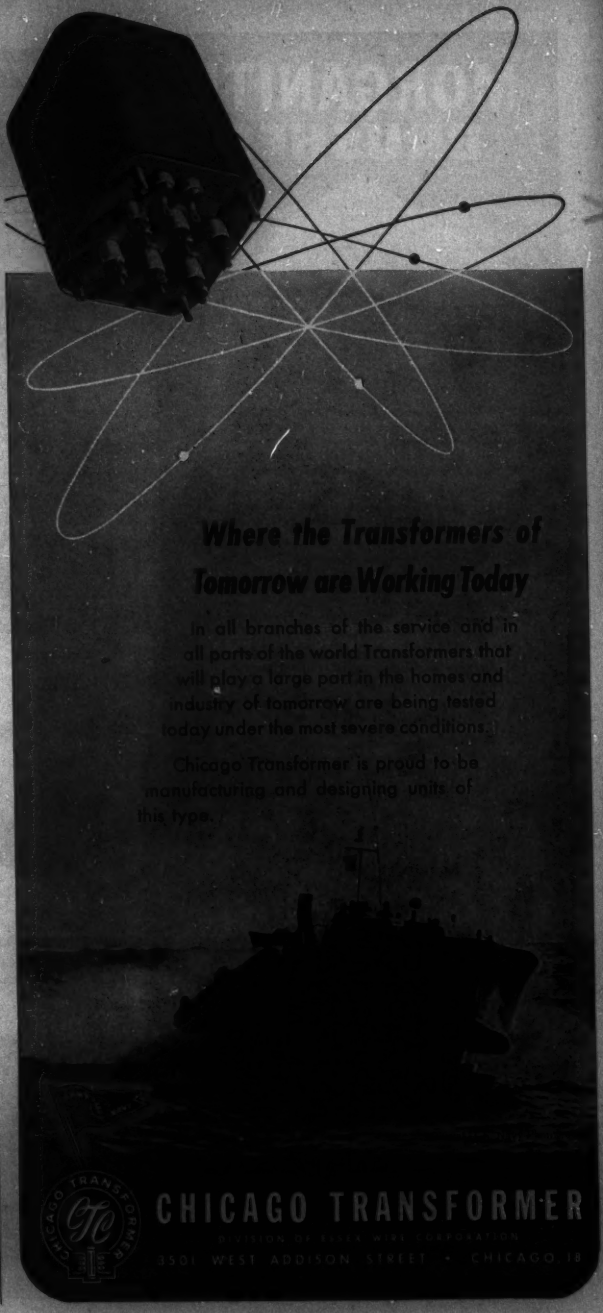
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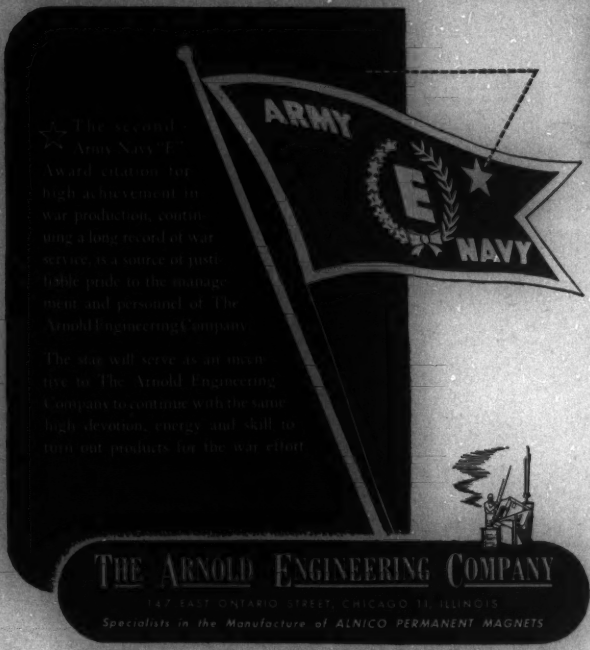

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With the advent of war, the ingenuity and resourcefulness of the NEW YORK TRANSFORMER Sample Department kept pace with the unprecedented demands of Army, Navy and Air Forces.

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6 "EXTRAS" GIVE LONG, UNINTERRUPTED LIFE TO TRANSTATS' SMOOTH CONTROL

Well known for their potentiometer smoothness and transformer efficiency, TH Transtat A. C. Voltage Regulators are strikingly demonstrating another quality—long, trouble-free performance.

The cut-out view above reveals some of the reasons for Transtat ruggedness:

(1) VARNISH IMPREGNATED CORE AND COIL form a solid mass that will not loosen in service.

(2) ADEQUATE TURN-TO-TURN INSULATION AND SOLID INSULATING MATERIAL between commutator bars assured by combination of extra wire insulation and varnish impregnation.

(3) BROAD, UNIFORM COMMUTATING SURFACE results from grinding commutator track on the parallel, uniformly spaced wires of the outside, cylindrical portion of the coil.

(4) SMOOTH, COMMUTATING SURFACE: no bumps jar the brush to cause breakage or arcing.

(5) LONGER BRUSH provides sturdiness, larger heat dissipating surface, and a greater contact area that reduces the current density per square inch of brush contact.

(6) BALANCED COLLECTOR ARM maintains brush setting when mounted in any position.

These features assure long, dependable life for Transtat Voltage Regulators. Yet Transtats are no more expensive than many other voltage regulating devices. For a continuously adjustable voltage or a constant voltage from a fluctuating source, specify Transtats. Write today for complete information covering manually operated Transtats. Ask for bulletin 51-2N.

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Selenium Corporation of America photo-electric cells are of the self-generating type and are manufactured to highest sensitivity and permanence standards. All S. C. A. self-generating cells can be used in a range from −70° C. to +70° C. and are rendered permanently stable by a special forming process. The most modern methods and equipment available are used in the manufacture of S. C. A. products. All cells and types, thoroughly inspected and matched with regard to sensitivity, spectral response, etc., are available.

S. C. A. makes photo-electric cells, mounted and unmounted, in over 30 standard sizes. Many of these standard types can be shipped from stock.

Write for special technical Bulletin on photo-electric cells and Selenium Rectifiers with output from 100 micro-amperes to 1000 amperes.

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HOW TO SELECT PHOTOTUBES

PHOTOTUBES have found such a wide variety of applications that many types have been developed to meet special needs. The complete RCA line includes both gas-filled and high-vacuum phototubes, with various spectral responses and a variety of sizes and shapes. And for applications requiring extreme sensitivity, RCA supplies multiplier phototubes.

A phototube acts as a light-actuated electric valve. (It does *not* convert light energy to electrical energy, but acts only as a control device.) The current passed is in proportion to incident light. Some phototubes are "high-vacuum" types; some are filled with an inert gas (such as argon) to increase current-carrying capacity.

A multiplier phototube contains additional electrodes (dynodes) which emit secondary electrons and thus greatly increase sensitivity and output current as compared to 2-electrode phototubes.

Color Sensitivity: The cathode coating material and the envelope glass determine color sensitivity. RCA phototubes fall into five "color groups":

Use	Tube Types	Maximum Color Sensitivity
With incandescent lamps	High vacuum: 925, Gas-filled: 868, 928, 934, 927*, 828	Red and infra-red
With incandescent lamps—and for infra-red application	High vacuum: 917, 919, 922*. Gas-filled: 918, 921*, 923, 930*	Similar to above, but sensitivity extended further into infra-red
With light source for colorimetry application	High-vacuum: 920	Blue light. Approximates the human eye
With daylight, carbon-arc, or mercury-vapor light source	High-vacuum: 929*, 934, Multipliers: 931-A*, 1P21	Blue light. Very sensitive to incandescent light at a color temperature above 2700°K.
For ultra-violet measurement	High-vacuum: 935, 1P28	Same as above, but special glass envelope permits high ultra-violet sensitivity

*An RCA Preferred Type Tube

Color response curves are available on all RCA phototubes.

Vacuum- or Gas- or Multiplier-Type? Several important factors to be considered in selecting the general type of phototube for a service are given in the following table. Specific values should be considered in selecting the actual tube type.

Characteristic	High-Vacuum type	Gas-filled type	Multiplier type
Sensitivity	Low	Medium	Very high
Current Output	Low	Medium	Very high
Amplification factor	1	Up to 10	Up to 1,000,000
Relative signal-to-noise ratio (including amplifier stage)	Low	Intermediate	High
Anode Volts	Up to 300	Not over 90	Up to 1250
Distortion (audio)	Negligible	Appreciable in some cases	Negligible
Frequency Range	Limited largely by circuit	Limited by tube performance	Limited largely by circuit

Gas-filled phototubes are, at present, extensively used for sound-on-film reproduction and for relay work. Vacuum-types are widely used where high sensitivity is needed; for precision measurement where stability of calibration is essential; and for high-speed work.

Sensitivity: The sensitivity of a phototube may vary according to whether the light change is abrupt or continuous. *Static sensitivity* is the ratio of anode direct current to constant light flux. *Dynamic sensitivity* is the ratio of the variation of anode current to the variation of light input. The sensitivity of gas-filled phototubes drops off as light-source frequency increases.

Optical Systems: The use of phototubes usually involves some sort of optical system. The fundamentals of optics must be carefully considered in the successful application of phototubes.

Mechanical Features: As illustrated at left, several types of tubes are available. Size, vibration, directional requirements, etc., all may influence the choice of one of the many RCA phototubes.

Phototube Life: Phototubes are inherently sturdy, long-lived tubes and when operated under recommended conditions, give extended reliable service.

Application Hints: Here are a few general suggestions on applying phototubes:

1. In relay and measurement circuits where tubes must respond to very small amounts of light, avoid leakage currents outside tube. Keep tube terminals and sockets clean. Erratic leakage currents will affect results.
2. In amplifiers where low leakage is important, select top cap types such 917, 919, or 935.
3. Shield phototube and leads to amplifier or relay tubes when amplifier gain or phototube load resistance is high.
4. Where high-frequency response is important keep phototube leads short to minimize capacitance shunting of output.
5. For constant calibration of high-precision vacuum phototube devices, keep anode voltage at or below 20 volts. Keep incident light spread over wide cathode area.
6. Design or circuit constants should be based on tests with the equipment operating over the expected range of line-voltage variation.
7. RCA voltage-regulator tubes can improve phototube circuit performance.
8. Anode characteristic curves on phototubes can be used to predict performance under given operating conditions.

What Phototube Do You Need?

Due to space limitations, the suggestions presented here are brief and in a condensed, summary form. If you have a specific application problem or wish to discuss your phototube requirements with us, write to RCA, Commercial Engineering Section, 716 S. Fifth Street, Harrison, N. J. For further published information on RCA Phototubes and how to use them, send the coupon at left.

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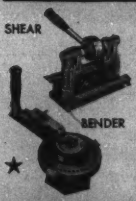

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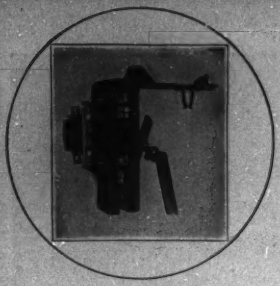

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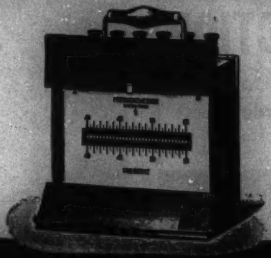

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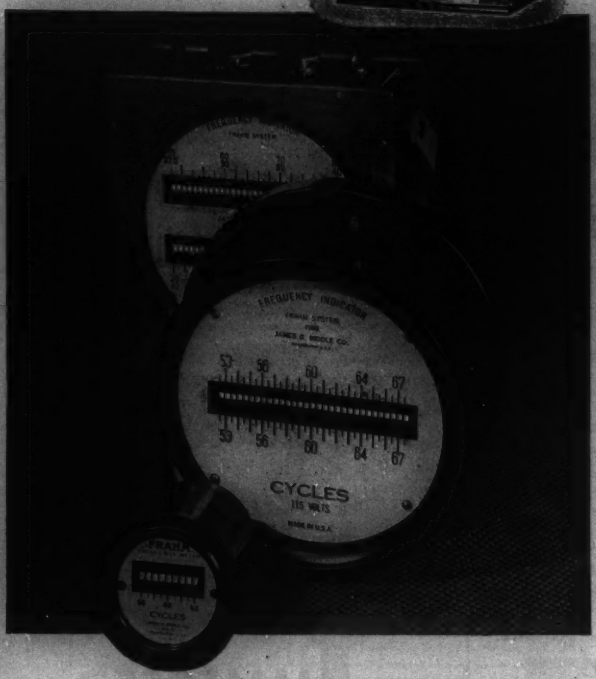

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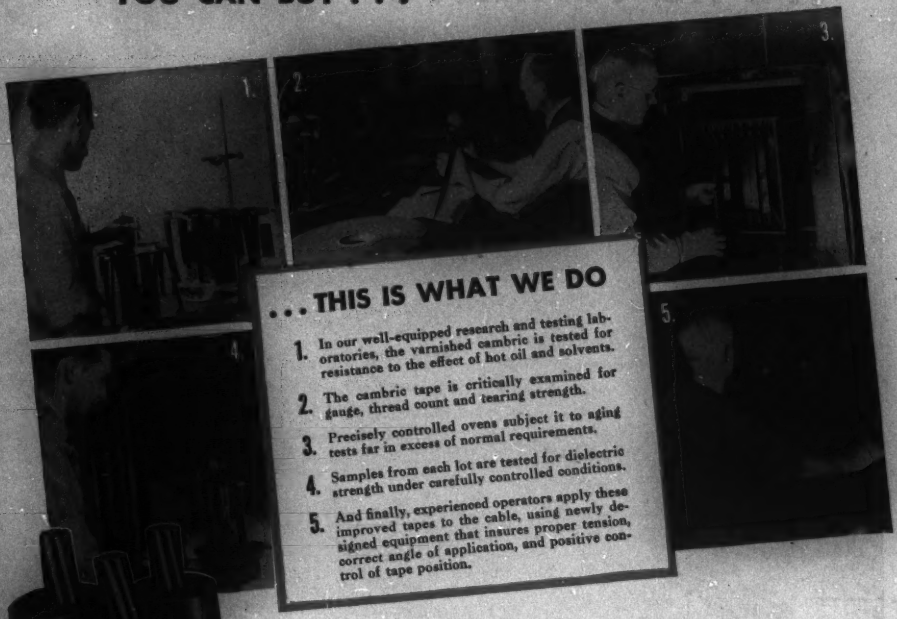

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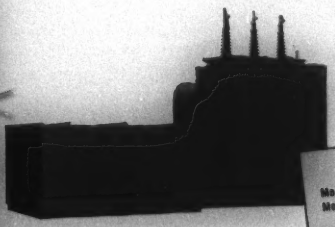

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